# NATIONAL RESEARCH COUNCIL

## AMERICAN GEOPHYSICAL UNION

## TRANSACTIONS OF 1939

## PART III

## TWENTIETH ANNUAL MEETING

APRIL 26 TO 29, 1939
WASHINGTON, D. C.

## REPORTS AND PAPERS
## GENERAL ASSEMBLY AND SECTIONS OF GEODESY, SEISMOLOGY, METEOROLOGY, TERRESTRIAL MAGNETISM AND ELECTRICITY, OCEANOGRAPHY, AND VOLCANOLOGY

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# INTRODUCTION

The American Geophysical Union was established in 1919 as the American Committee of the International Union of Geodesy and Geophysics, and its Executive Committee is the Committee on Geophysics of the National Research Council. The objects of the Union are to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of these objects, the Union is divided into sections following the plan of organization of the International Union of Geodesy and Geophysics. There are now seven sections, namely, (a) Geodesy, (b) Seismology, (c) Meteorology, (d) Terrestrial Magnetism and Electricity, (e) Oceanography, (f) Volcanology, and (g) Hydrology. A Section of Geophysical Chemistry was discontinued May 31, 1924, as the International Union had failed to provide such a Section; the Section of Hydrology was established November 15, 1930--matters pertaining to scientific hydrology referred to the American Geophysical Union had been previously looked after by special committees on Hydrology.

Annual assemblies of the Union and annual meetings of its sections for the discussion of reports and for symposia are held each year. The first 13 assemblies and meetings--those in each of the years from 1920 to 1932--were held in Washington, D. C. Besides the annual general assemblies and meetings of each of the seven sections held in Washington, D. C., meetings of the Section of Hydrology were held at Berkeley, California (1933 and 1934), at Pasadena, California (1936), at Denver, Colorado (1937), at Spokane, Washington (1937), at Davis, California (1938), at Los Angeles, California (1938), and at Spokane, Washington (1938). The transactions of annual assemblies and meetings through the ninth were published in the Bulletin series of the National Research Council as follows: Second, 1921, Bulletin No. 17; fourth, 1923, Bulletin No. 41; sixth, 1925, Bulletin No. 53; seventh, 1926, Bulletin No. 56; eighth, 1927, Bulletin No. 61; and ninth, 1928, Bulletin No. 68. Transactions of the tenth and eleventh annual meetings held in 1929 and 1930 were published in one volume in June 1930, and those of the twelfth, thirteenth, fourteenth, fifteenth, sixteenth, seventeenth, eighteenth, and nineteenth annual meetings were published in June 1931, June 1932, June 1933, June 1934, August 1935, July 1936, July 1937, and August 1938, respectively, in the series of miscellaneous publications of the National Research Council. The present volume, in four parts, also one of the miscellaneous publications of the Council, includes the transactions of the twentieth annual meetings held at Washington, D. C., April 26 to 29, 1939 (Parts II, III, and IV), and of the meetings of the Section of Hydrology at Los Angeles, California, December 16 to 17, 1938, and at Spokane, Washington, December 28, 1938 (Part I). At the first, third, and fifth annual meetings in 1920, 1922, and 1924, respectively, there were no scientific papers presented; therefore, the transactions for these were not printed but were mimeographed for limited distribution only.

Part I(A) is devoted to the joint South Pacific Regional Meeting at Los Angeles, California (December 1938) of the Section of Hydrology and of the Western Interstate Snow-Survey Conference; there were 27 papers and reports presented at this meeting. Part I(B) is devoted to the joint North Continental Divide Regional Meeting at Spokane, Washington (December 1938) of the Section of Hydrology and of the Western Interstate Snow-Survey Conference; there were 12 papers and reports presented at this meeting. Parts II, III, and IV contain the papers and reports presented at the twentieth annual meetings of the Union at Washington in April 1939. Part II includes the 14 papers presented before the Section of Hydrology in a "Symposium on floods"; Part III includes the reports and papers presented before the General Assembly and all of the Sections except that of Hydrology; Part IV includes the reports and papers presented before the Section of Hydrology.

As in the published volume for 1938, the minutes of the General Assembly and of those of the sections, with their appendices, have been added--in Part III--in the Transactions for the twentieth annual meeting. The total attendance of members and guests at Washington was in excess of that registered, namely, 497--an excellent indication of the value of the Union in the progress of geophysics in the United States. The attendances at the regional meetings also emphasize growing interest in the United States in the activities of the Union's Section of Hydrology.

Included in these minutes are the reports of officers and of standing, special, and research committees. Especially noteworthy are those of the newly-formed Special Committee on Cosmic Terrestrial Relationships and of the two committees on Geophysical and Geological Study of Oceanic Basins and on Geophysical and Geological Study of Continents; all three give abundant evidence of progress.

Seven resolutions were adopted at the General Assembly. The subjects of these were as follows: Long-range weather forecasts; geophysical and geological study of oceanic basins; geophysical and geological study of continents; seismological activities of the Eastern Section of the

Seismological Society of America; Naval Observatory time-signals; and two resolutions of thanks for cooperation of the Smithsonian Institution and of the George Washington University.

A feature of the twentieth annual meeting of the Union was the announcement of the William Bowie Medal, endowed by friends and coworkers of Dr. William Bowie and established by vote of the Executive Committee of the American Geophysical Union on March 1, 1939, to be awarded for distinguished attainment and outstanding contribution to the advancement of cooperative research in fundamental geophysics. The first Medal was presented to Dr. William Bowie April 28, 1939. Following this award, there was a "Symposium on geophysical prospecting" of eight papers. These concerned petroleum and mining exploratory methods, photographing of sections of boreholes, telluric currents and prospecting at surface, radioactivity for stratigraphic studies, and governmental activities in geophysical prospecting. The published papers form an excellent general view of this subject.

At the session of the Section of Geodesy eight papers and reports detailed progress along geodetic lines as follows: Relation of inch and meter; procedure at triennial assemblies of the International Association of Geodesy; astronomic work on delineation of boundaries; relation of physiographic provinces to topography; new methods of representing terrain; and progress-reports on geodetic work in Mexico and the United States of America.

The Section of Seismology held only one short session at which procedure at triennial assemblies of the International Association of Seismology, and arrangements for the coming Assembly at Washington of that Association, were discussed.

The seven papers and discussions before the Section of Meteorology were concerned largely with upper-air developments. Among these were: Measurements and origin of ozone; research concerned with air-navigation over the Atlantic Ocean; factors controlling winter-time precipitation; upper-air observations in the Pacific; precipitation and low temperatures aloft; and sidereal barometric-pressure wave.

Two extended sessions of the Section of Terrestrial Magnetism and Electricity heard 22 papers. These were concerned with the following subjects: Instrumental features (5); secular variation (3); the Earth's quadupole moments (1); cosmic radiation (3); auroral phenomena (3); solar and ionospheric relations (2); atmospheric electricity (2); earth-currents (2); procedure at triennial assemblies of the International Association of Terrestrial Magnetism and Electricity (1). Besides these papers, four progress-reports were received on magnetic activities in Mexico and the United States of America.

The Section of Oceanography was given over largely to five progress-reports of Federal and private organizations. Two papers discussed the influence of turbulence on the characteristics of waters at mid-depths and the new bathymetric chart of the Caribbean Area.

Seven communications to the Section of Volcanology related to the Tuscan Soffioni, crystallization of a basaltic magma, Borabora lavas, features of basaltic flow, grooved lava, the Livingston formation, and volcanic sequence in Utah.

The Section of Hydrology, in four sessions, had a lengthy and valuable program. The 15 reports and appendices of the Section's standing research committees and subcommittees showed splendid progress and included lengthy bibliographies and abstracts. Besides these reports, 16 papers were presented; these discussed observational and experimental data on rivers, wells, subterranean water, soil-moisture, drainage-basins, evaporation, infiltration-capacity, rainfall, and runoff.

The General Secretary edited the manuscripts for publication after some preliminary editing by the secretaries of sections and by the chairmen and Dr. J. E. Church for the regional meetings. The present Transactions include, either in full or in abstract, 114 papers and reports presented during the twentieth annual meeting at Washington and 39 papers and reports with discussions presented during the meetings of the Section of Hydrology and of the Western Interstate Snow-Survey Conference at Los Angeles and Spokane. The cost of publication was met through allotment by the National Research Council for maintenance of the Union, annual dues of members of the Union, and contributions of money and of services from the Carnegie Institution of Washington, from the University of Nevada, from members of the Union, and especially from hydrologists both members and non-members. Each of the authors, except for a few who could not be reached, revised his matter as prepared for publication. The final copy was prepared by J. J. Capello, W. E. Scott, and R. O. Alpher, and was planographed by the Kirby Lithograph Company of Washington. Besides its obligation to authors, to members of committees, and to our colleagues in

Canada and Mexico, who contributed to the twentieth annual meeting, the Union is indebted to W. C. Hendrix for preparing many drawings of which the originals submitted were not suited for planographic reproduction and to P. G. Ledig for photographic work.

Realization in September 1939 of the plans of the Union, in collaboration with the National Research Council, and with generous contributions from the Federal Government through the Department of State, the Carnegie Corporation of New York, the Geological Society of America, the National Research Council, several scientific societies, and friends and members of the Union, for the Seventh Triennial Assembly of the International Union of Geodesy and Geophysics--the first to be held in the United States of America since that body's organization--should do much to advance the scientific and economic aspects of geophysical research and the coordination of International and National activities.

Jno. A. Fleming, General Secretary,
American Geophysical Union

# AMERICAN GEOPHYSICAL UNION

Twentieth Annual Meeting

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## GENERAL ASSEMBLY

Washington, D. C.
April 28, 1939

## SYMPOSIUM ON GEOPHYSICAL PROSPECTING

ORGANIZED BY THE COMMITTEE ON GEOPHYSICAL METHODS OF EXPLORATION OF
THE AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
IN COOPERATION WITH THE AMERICAN GEOPHYSICAL UNION

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# SYMPOSIUM ON GEOPHYSICAL PROSPECTING

Organized by the Committee on Geophysical Methods of Exploration of
the American Institute of Mining and Metallurgical Engineers
in cooperation with the American Geophysical Union

## GEOPHYSICAL METHODS IN PETROLEUM-EXPLORATION

J. Brian Eby

As is generally understood, the word geophysics means literally "the physics of the Earth" and the science of geophysics is therefore that which treats of the study and measurements of the various physical properties of the Earth. The broad and general study of the elastic, the gravimetric, or the magnetic properties of the Earth as a whole belongs to the general science of geophysics. The detailed application of this science to rocks of shallow depth and in small areas for the purposes of ascertaining data on their character and structural attitude gave rise to the present well-known science of "applied geophysics." Since the discovery of enormous new quantities of oil, gas, and sulphur has been by far and wide the principal benefaction of geophysics in the United States, this paper will refer only to geophysical methods employed in the search for these particular minerals.

The application of methods and appliances originally used for geophysical research to the solution of the practical problems of finding new oil-fields, plus the counterflow of new and highly refined techniques and instruments from the company and consulting geophysical research laboratories and into non-economic geophysical research, has provided another case of that general cycle of events which is familiar to all scientists.

That this closed-circuit flow of scientific current has been tremendously important to the whole science of geophysics is probably well known to all members of this audience, but the general status of the exploratory geophysical arts as now used in the search for new oil-fields, the scales on which different methods are being used, the magnitude of the costs involved, and the far greater magnitude of the practical results achieved may not necessarily have come so directly to your attention. It is, I understand, for this reason that this paper has been suggested, and I shall seek to provide the information requested by using as case-illustrations those changes in the oil-reserve picture for the United States as a whole, and for the Gulf Coast, California, and Illinois Basin regions in particular, which have occurred in the period of the past 17 years, during which time oil-field discoveries have proceeded at a rate which served to build up known and readily-available (or proven) oil supplies to a reasonable figure, and have dispelled the fears of a serious oil shortage during any period for which valid forecasts can be made. Not that geophysical-prospecting methods have alone been responsible for this transformation, but they have an indispensable and leading part in the picture of exploration and production--to which geophysics, geology, engineering, and general technical progress have jointly made contribution. So far as the United States as a whole is concerned, its total proven, probable, and possible oil reserves (discoverable and recoverable by then-known methods) were estimated at about nine billion barrels in 1920, whereas proven reserves alone are now computed at about 16 billion. In 1920 the driller in "wild-cat" territory was faced with the knowledge that for every new oil-field opened by a successful well, from 20 to 100 unsuccessful wells would have to be drilled and, in some territories, that the chances for a discovery were really less than one in 100 for new drilling, in contrast to which may be cited the record for the past year in parts of Louisiana where the 67 wells drilled opened 16 new oil-fields, that is to say, where the score of hits to misses was increased to approximately one out of four.

To illustrate more specifically what has been accomplished by geophysical-prospecting methods in the Gulf Coast region of Texas and Louisiana, beneath which there are perhaps 25,000 to 40,000 feet of layered clays and sands, these sedimentary beds slope gently Gulfward and locally have been pierced by cylindrical or oval stocks of salt which have risen to, or almost to, the surface, or which have spread out like hidden mushrooms at greater or less depth. Oil, gas, (and sulphur) occur in the limestone "cap-rock" overlying such salt domes, and oil and gas also occur in sand beds arched above the top of the deep-seated salt bodies and in the flank sands which are upturned around the edges of the piercing salt core. Individual domes may yield amounts of oil in excess of 100,000,000 barrels, and it is even probable that some may produce several hundred million barrels. The search for such "structures," and for other types of oil-containing "traps" in the Gulf region, has therefore, been intensive and extensive, and has taken place in four periods.

During the period extending from the drilling of the Spindletop dome in 1901 to 1923, exploration was guided by recognizable surface mounds, gas seeps, "salines," and other geological indications, and, according to Rosaire, 31 oil-fields were opened by the hundreds of wells drilled on geological evidence, on hunches, and on the "magic" of "doodlebugs" and "wigglesticks."

By 1920, however, the costs of discovery, solely on such evidence had become well-nigh prohibitive, and consequently experimentation with the Eotvoes torsion balance was begun in 1922 and the refraction-seismograph was brought in in 1923, with the result that 51 new oil-fields, largely on domes of moderate depth, were made on geophysical and geological-geophysical evidence between 1923 and 1932. During the third period, from 1932 to 1938, the use of the reflection-seismograph has attained a dominant position, though the torsion balance continued to be extensively used; some additional refraction-work was done; magnetic and electrical methods were tried, the gravity-pendulum was employed, and static gravity-meters, "electrical transient," and soil-analysis methods were "in process." During this period of seven years, 116 discoveries resulted, in comparison with 61 in the previous nine-year period and 31 in the antecedent 22 years. About the beginning of 1938, the static gravimeter began to come into prominence as a reconnaissance-method, and began to curtail the use of the torsion balance; new adaptations of the reflection-seismograph for profiling were developed, and seismometer-assemblies of new types and sensitivities were developed; a number of organizations went more actively into soil analysis; and new electrical-type methods and other variations and refinements were devised (not all as yet publicly announced) due to which Rosaire has predicted that the 10 years ending 1948 should show discoveries of some 200 new fields--chiefly large, deep-seated domes of low relief, grading over into shore-line sand wedges and similar "stratigraphic" traps, where the up-dip termination of the porous bed is responsible for localization of the oil pool. There is indication, then, that the rate of discovery based on combined geophysical-geological exploratory techniques is, if anything, moving at an accelerated pace--obviously with enormously important consequences to the oil industry (and public) and with perhaps less obvious, but equally great importance to geophysicists interested in non-commercial explorations in suboceanic regions and in the deeper parts of the Earth's crust.

To illustrate this briefly, let us review for a moment the development of some of the geophysical-prospecting arts and instruments. In the case of the torsion balance, it is still customary to mount two systems within the instrument at 180° and to take three sets of readings at three azimuths at each station. Recently a short-period balance has been introduced, with electrical recording of observation, greatly accelerating and simplifying operations--especially on swampy terranes. This balance, as you know, measures the horizontal gradient of gravity and provides data for computing the differences between the principal radii of curvature of the gravitational field, and these instruments must be sensitive to 1 Eoetvoes, or $10^{-9}$ dynes per centimeter.

During 1930 and 1931 gravity-pendula were developed with a sensitivity of 0.0002 cm per second per second, but it was necessary to determine the period of these instruments to $10^{-8}$ seconds, and difficulties arose due to the instability of supports and the necessity of swinging the pendulum for at least one hour. (Therefore, while such instruments should be very valuable for general geophysical-geological research, they have been largely superseded for practical purposes by the static gravimeter.) These began to be introduced in 1932 and are now in wide use. In these meters, the force of gravity on a weight is balanced by some force which is a function of the displacement of the weight but not of gravity. It is customary to design the meter so that its equilibrium position is near a point of unstable equilibrium in order that small changes in the force of gravity will produce relatively large changes in the displacement. Either by optical magnification or by electrical means, the displacement is observed. At present, gravity-meters suitable for prospecting have a usable sensitivity of one-tenth milligal, that is, an acceleration of $10^{-4}$ cm per second per second. The time required for observation at each station is of the order of two to five minutes, and the meter gives the difference in gravitational acceleration between the two stations which is the equivalent of the pendulum measurement.

Seismic prospecting in the United States began in 1923 with the introduction of the refraction-seismograph into oil-field exploration. In the first refraction-work, mechanical seismographs were used which could record motions of $10^{-4}$ inches, and it was necessary to measure time to somewhat better than one one-hundredth of a second. Later electrical seismographs were employed with a sensitivity of perhaps 10 to 100 times that of the mechanical seismographs. In the refraction-method, only the first arrivals were used. The present electric seismographs record motions of $10^{-7}$ inches, and amplifiers are used with an amplification as high as 500,000. These amplifiers are designed to select certain frequencies, usually from 25 to 150 cycles. Times must be measured with an accuracy of one-thousandth of a second.

Starting as early as 1926, American geophysicists, led by Rosaire, McDermott, Karcher, and McCollum, experimented with the idea of reflection-seismograph exploration. The principle in general consists of sending an impulse or shock vertically, or nearly so, into the ground and recording reflections of energy from any particular plane or bed competent to send back such a reflection or "echo." The difficulty of identifying reflections was made easier by the invention of multiple recorders, namely, taking several seismograms on one photographic tape.

The invention and perfection of reflection-shooting marks the greatest single achievement in seismograph-exploration since the original development of the method. It was a long and difficult task, however, and did not reach the peak of unanimous approval and success until 1934. It was this year that two outstanding oil-fields--Hastings, in Texas, and English Bayou-Gillis, in Louisiana--were brought into production as a result of prospects outlined by reflection-shooting. From 1934 to the present, this method of exploration has been carried over the whole coast, the Mid-Continent, California, Illinois, and other parts of the United States. By a series of brilliant oil-field discoveries, it has established itself firmly as one of the most potent arms of the exploration-industry.

The magnetometer was first introduced into the United States about 1922. It has since that time been employed extensively in the search for serpentine plugs and in outlining structures in the surface of the basement-rocks. It has been used to a small extent in the search for salt domes in the Gulf Coast.

As a rule, magnetometers of the Schmidt type are employed; only the vertical component of the Earth's field is measured, but a few companies have made observations on both components. The required sensitivity is about two gammas (one gamma is equal to $10^{-5}$ gauss). On account of the diurnal and other variations in the Earth's magnetic field, it is necessary to use a base-station, where an instrument is permanently located in the area under investigation, if accurate and reliable data are required, hence always in the search for small anomalies.

Electrical prospecting with direct currents, and with alternating currents of either low or high frequencies, have been widely used in locating isolated bodies of different electrical properties, for locating faults, and for determining the dips of strata. Since 1933, measurements have been made which employ electrical transients in the ground. In all of these measurements, potentials of the order of one or two millivolts must be measured.

The use of electrical resistivity-measurements in deep uncased wells to determine the presence or absence of oil, gas, and salt water, and the porosity of sand bodies has reached such a phenomenal success as to be of tremendous economic importance. Schlumberger of Paris and Halliburton of the United States have perfected the art of electrical well-logging to a truly remarkable degree. It is regretted that only mention of the method can be made in this paper.

From time to time, measurements of radioactivity have been made by means of electrometers. No wide-spread commercial application of this method exists. Likewise, measurements of near-surface temperatures have been made from time to time with either mercury thermometers capable of reading to an accuracy of about one-tenth degree or with electrical thermometers with corresponding sensitivity. This method likewise does not have wide-spread commercial value.

Since 1933, measurements of the amount of hydrocarbon content in soil gas have been made. These quantities must be measured with an accuracy of two or three parts per million by volume. In another method the soil is analyzed for various materials, such as wax and mineral content. Little definite information is available concerning the method of analyses, and the research has not yet definitely established its commercial application.

The use of geophysical instruments has spread to all parts of the United States that give any promise whatever of oil occurrence. In recent years the development of the Illinois basin has been almost entirely due to the advent of reflection-seismograph work. In California important new oil-fields have only recently been added by the use of the seismograph. Even now far in advance of any indication of oil or gas, geophysics is being pushed into Alabama, Georgia, and Florida.

In California during several years prior to 1936, the State actually produced more oil than was discovered, and only one major discovery (Mountain View) had been made since 1928 (Kettleman Hills and Elwood). Therefore, in 1935 it became generally recognized by California oil executives that newer and more costly exploratory methods and programs must be utilized, and this recognition, coupled with the introduction of improved seismographic instruments--chiefly for reflection-work--have resulted in the discovery during the three years 1936-1938 of 16 important oil-fields, with total proven reserves of about one and one-half billion barrels of oil. Especial importance attaches to the discovered fields and prospects concealed beneath the flat and featureless floor of the San Joaquin valley where no direct (surface) geological evidence is available, and geological interpretation of the results yielded by reflection-shooting have been chiefly responsible for the numerous successes registered.

In Illinois, a proportionately more striking rejuvenation has been wrought in the "oil picture" in the past two years. Decline of the old Illinois fields had so far progressed that the State had dropped from major rank in the United States to where it was producing a few thousand barrels per day or about 0.3 per cent of the national output. Large areas within the State had been pointed out by the State Geological Survey as potentially promising for oil-field discovery, but the hazards attendant on selecting specific drilling locations on geological evidence alone were so great that prospecting was almost at a standstill. until the introduction of the torsion balance and much more particularly due to the introduction of the reflection-seismograph about 1935. With the usual two-year lag, the first discovery based on this work was completed in 1937. Some 16 or 17 fields and numerous prospects have been discovered on geophysical and geophysical-geological evidence, the State's daily output has risen to about 160,000 barrels--a twentyfold increase--and the estimated reserves of the State have grown from a computed 30 million to 300 million barrels.

Comparable, though less spectacular, aids to discovery have been received from geophysical-prospecting methods in the search for oil and gas in various parts of the United States.

Further, the question of the relative values of the different methods in different regions is too broad to discuss in a paper devoted largely to a summary of actual methods. Each of the methods has particular advantages which, if properly considered, will yield proportionately better results. Geophysical costs range from a few hundred dollars a month to operate the ordinary magnetometer to nearly one thousand dollars a day to operate the refraction-seismograph. Torsion-balance operations average three to five thousand dollars monthly, depending on terrain. The specific problem of geophysical operations and results to kind of methods and costs should be referred to practicing geophysicists. In the Gulf Coast of Texas and Louisiana alone from 1923 to date, well over $100,000,000 has been expended in petroleum geophysics, with perhaps an equal expenditure in the rest of the United States. The rewards, however, have been far greater, for, to date, geophysical work has been indispensable to the discovery of at least 20 to 25 per cent of the 16 billion-barrel proven oil reserves of the United States, without any allowance for the possible yields of dozens of "geophysical prospects" which are as yet untested by the drill.

Applied geophysics in the petroleum industry is indeed "big business."

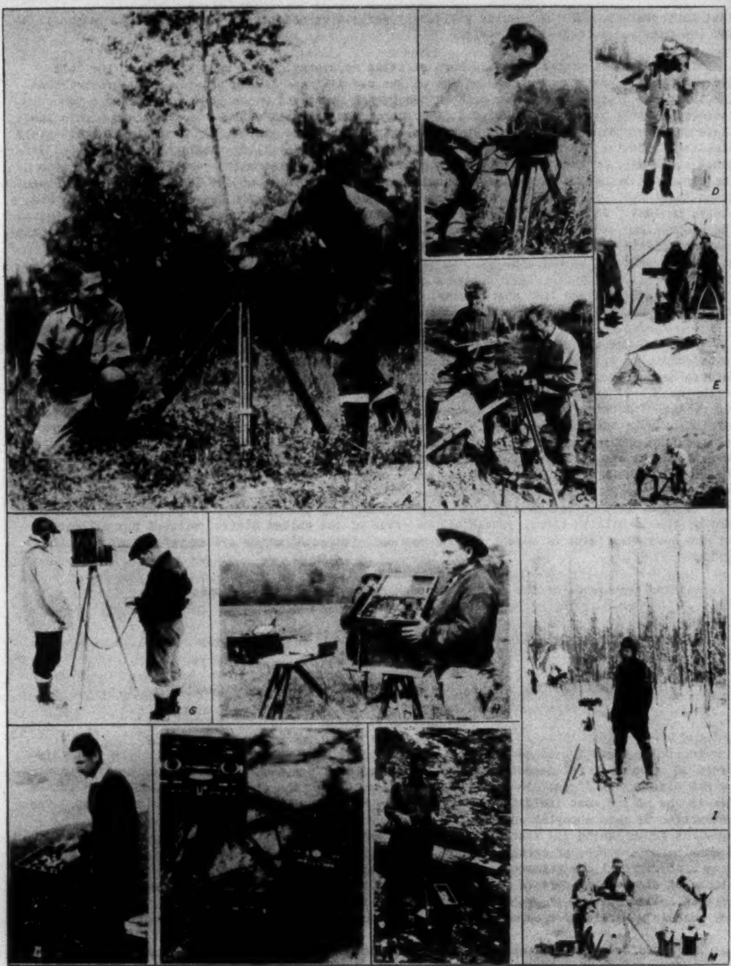
P. O. Box 962,
Houston, Texas

## GEOPHYSICAL DELINEATION OF STRUCTURE IN MINING EXPLORATIONS

Sherwin F. Kelly

The prime objective of geophysical exploration is to promote the economical and rapid discovery of mineral or oil deposits of commercial value. To a few this concept as applied in mining may signify the direct discovery of ore-bodies, but to the geophysical engineer this latter idea is one of the most insidious and detrimental misapprehensions which he has to combat. The destruction of this annoying obstacle to the progress of geophysical exploration reveals the kernel of truth behind it, that the exploration geophysicist has for the better part of two decades been concerned primarily with the discovery of mineral formations favorable to the occurrence of commercial ore. There is a very real distinction here, since geophysical methods are capable of discovering certain mineral formations such as sulphide bodies or quartz veins, but are totally incompetent to predict whether or not they constitute ore; that is, whether or not they contain minerals of economic value in the amounts requisite to repay extraction.

The art of geophysical exploration is now, however, rapidly outgrowing these early limitations. The rate of this growth will in large measure depend on the recognition by the mining industry of the fact that geophysics can play a role far wider and more important than it usually does now, in guiding the future exploration and development of mineral deposits. It is my own firm conviction that as time marches on we will see the methods of applied geophysics turned more and more to the delineation of both minor and major structural features. The outlining of such features having a bearing on the probable loci of mineral deposition will be of inestimable value in guiding the development of a mining district. It is in this field that there will inevitably occur a meeting and overlapping of the activities of the exploration geophysicists and



*GROUP OF INSTRUMENT-AND FIELD-VIEWS: (A) HOTCHKISS SUPERDIP; (B,C) SCHLUMBERGER ELECTRICAL RESISTIVITY-APPARATUS; (D) ASKANIA VERTICAL MAGNETIC BALANCE; (E) GROUND-COMPARATOR ON ICE, KELLY LAKE SURVEY; (F) PROSPECTING FOR SULPHIDES IN MEXICO; (G) LUNDBERG ELECTRICAL PROSPECTING APPARATUS; (H) MEGGER GROUND-TESTER (LEFT) AND GISH-ROONEY RESISTIVITY-APPARATUS; (I) PROSPECTING FOR SULPHIDES IN CANADA WITH SCHLUMBERGER SPONTANEOUS-POLARIZATION APPARATUS; (J,K) GROUND-COMPARATOR; (L) GROUND-COMPARATOR ON STRUCTURAL STUDY IN CANADA; (M) GROUND-COMPARATOR ON RESISTIVITY-SURVEY IN MEXICO*

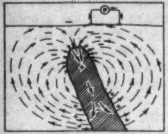


FIG. 1—FLOW OF ELECTRIC CURRENTS SPONTANEOUSLY GENERATED BY A SULPHIDE-BODY; CURRENT-PATH THROUGH MEASURING APPARATUS AT SURFACE ALSO INDICATED

of the geophysicists concerned with research on continental structure. I would have said the overlapping of the fields of applied and pure geophysics but the term "pure" geophysics is one I dislike, particularly since it seems to emphasize a distinction which is a false and misleading one; all geophysical investigations, whether "pure" or "applied," are directed fundamentally to the same end, that of deciphering terrestrial structures and phenomena.

I believe that the distinction between the two types of geophysical activity will eventually disappear, and we will find that the exploration geophysicist working in mining fields contributes much to the knowledge of earth structure, even as his brother in the oil-fields is already doing, and conversely that the geophysical revelations of continental structure will in time have a profound influence on the future search for districts likely to contain mineral deposits. This is admittedly but a vision of the future, but I hope to be able in what follows to indicate at least a few steps towards its fulfilment.

There is a wealth of material which I should like to use, but necessity compels the choice of merely a few typical examples to illustrate some of the steps involved in this expanding role of applied geophysics. I do not want to give the impression that this expansion is strictly a function of time because, at an early stage in the modern development of geophysical prospecting, surveys were made with the object of delineating important structural features. As geophysical methods become more firmly established in the mining industry, however, there is an increasing tendency to utilize them for these broader studies.

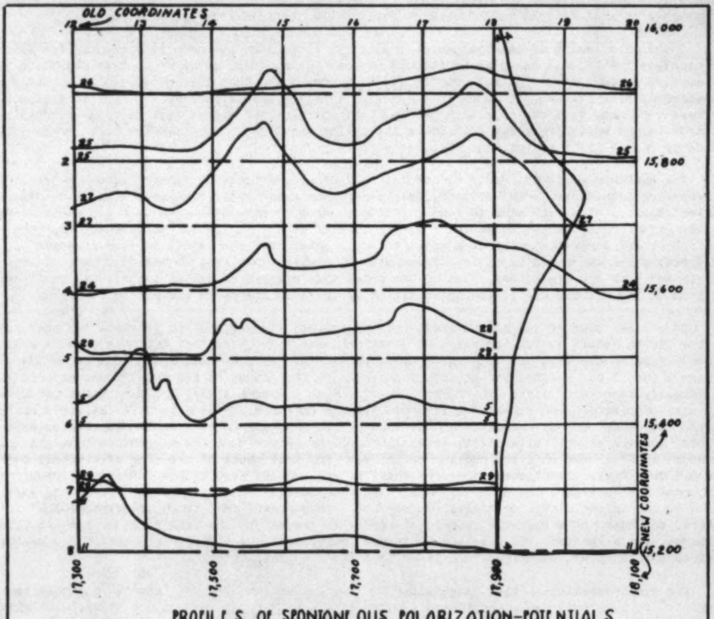
The narrower applications of electrical and magnetic methods to direct search for possible ore-bearing formations is an old story, far older than most people realize. Without delving into ancient history, I merely wish to remind you that magnetic compasses were used for the discovery of magnetite bodies in Sweden at least as far back as 1640. It was in that country that the Swedish miners compass was invented about 30 years later, for the avowed purpose of magnetic prospecting for lodestone deposits. These methods played their part in the discovery of iron ore in New York and New Jersey, some of the mines thus discovered having contributed their share of iron to the manufacture of the arms carried by American troops in the Revolutionary War.

Electrical prospecting cannot boast such an ancient lineage, but it is about 100 years old. In the 1830's Robert W. Fox, an English scientist, established the fact that there was a spontaneous flow of electric currents in the neighborhood of certain veins of sulphide in the mines of Cornwall [see 1 of "References" at end of paper]. In the course of his underground experiments he actually discovered a new lens of pyrite [2]. Some 50 years later, Dr. Carl Barus restudied the same phenomenon near Eureka, Nevada, his results appearing in 1882 in G. F. Becker's United States Geological Survey Monograph on "Geology of the Comstock Lode." In the conclusion of his chapter "On the electrical activity of ore bodies," Dr. Barus made the suggestion that this phenomenon could be used as a prospecting technique. The true cause of the flow of electric currents was not definitely established, however, until it was demonstrated by the independent researches of Conrad Schlumberger, Professor of Physics at the School of Mines in Paris [3], and of Roger C. Wells of the United States Geological Survey [4]. They showed that it was electrochemical in nature, dependent on a reaction between electrolytes present in the wall-rocks and the metallically conductive sulphides. To the late Professor Conrad Schlumberger goes the credit for having devised apparatus and technique to utilize this fact in prospecting.

The electrochemical action responsible for the generation of these "spontaneous polarization-currents" is apparently an accompaniment, to a certain extent, of the process of sulphide-oxidation. The flow of electricity is from the apex of the sulphide-body downward through its mass; at some point in depth the current emerges into the wall-rocks and flows back up to the surface on either side of the deposit; the circuit is completed by a centripetal flow of current into various "negative centers" situated along the apex of the vein or lens (Fig. 1). The exterior wall-rocks therefore correspond to the liquid circuit in an ordinary galvanic cell, while the sulphide mass itself is the wire connecting the poles of the battery. The action of this current is to liberate oxygen at depth, whereas hydrogen or other metallic ions are liberated at the pole near the surface. Thus it will be seen that the flow of current may promote deep oxidation, and facilitate the deposition of such substances as free metal in the zone of oxidation. Is this the explanation of metallic copper sometimes found in the gossan of copper ores? There is a fascinating field for speculation and research here on the role of spontaneous polarization-currents in the processes of oxidation and enrichment.

The observation of these phenomena in the field is carried out by making ground-contacts through the medium of two movable electrodes connected to a potentiometer. The latter instrument measures the voltage and shows the direction of flow of the current shunted from the ground through the measuring circuit. Normally, potentials of 100 to 600 or 700 millivolts will be observed over the apex of a sulphide body. When readings along various lines traversing a sulphide body are plotted as profiles, peaks of negative potential are observed above such mineralization. A series of these profiles can readily be transformed into an equipotential-map; in this, contour-lines connect points of equal electrical potentials. That is, the resultant map is a plan of the contours of the "mountain" of electrical activity centered on the sulphide body.

The modern practical application of this method dates back over 25 years to 1913, when Conrad Schlumberger carried out his early experiments on the deposits of pyritic iron at Sain-Bel in France. A zone of spontaneous electrical activity was found, corresponding to no known lens of pyrite. Subsequent exploration during the War encountered a pyritic body at the indicated place [3]. In the same year this technique was applied on the famous copper deposits near Bor, Serbia,

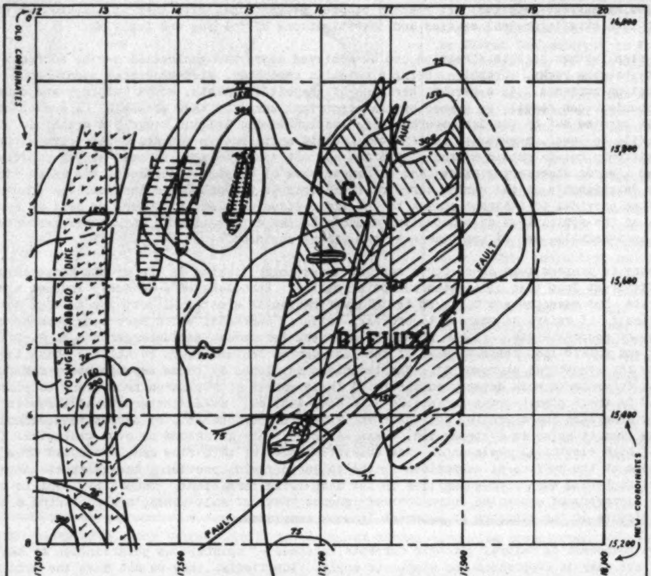


PROFILES OF SPONTANEOUS POLARIZATION-POTENTIALS
FROM A PORTION OF THE ELECTRICAL SURVEY
OF
NORANDA MINES LIMITED QUEBEC
BY
SULLIVAN & KELLY JUNE - JULY 1924

FIG. 2

and indicated a southward prolongation of the deposit beyond the limits then known [5].

It was this method which I introduced on the North American Continent in 1921 [6], the first important application being at the property of the Noranda Mines, Limited, in Quebec in 1924. Some of the ore-bodies were already known from drilling at the time of my work, but two new ones, the E and the G, were discovered as a result of the electrical survey. The G-body in particular was in a region where mineralization was not expected, and has produced about 700,000 tons of silicious fluxing ore for the smelter. The E-body has yielded some 300,000 tons of copper-gold ore. Figure 2 shows only that portion of the survey concerned with the area immediately around the G ore-body. Measurements were made along east-west profiles and one connecting profile


12
13
14
15
16
17
18
19
20
0
1
2
3
4
5
6
7
8
OLD COORDINATES
NEW COORDINATES
16,000
15,800
15,600
15,400
15,200
17,300
17,500
17,700
17,900
18,100
YOUNGER GABBRO DIKE
C
B (FLUX)
FAULT
75
150
300

EQUIPOTENTIAL-CURVES DEDUCED LATER FROM SPONTANEOUS POLARIZATION-PROFILES, COMPARED WITH SULPHIDE MINERALIZATION DISCOVERED ON BASIS OF PROFILE INDICATIONS FROM A PORTION OF THE ELECTRICAL SURVEY OF NORANDA MINES LIMITED QUEBEC

BY

SHERWIN F KELLY JUNE-JULY 1924

N

LEGEND

2 ┼ 12 — COORDINATE LINES AND NUMBERS

▭ SULPHIDE-MINERALIZATION AT SURFACE (DISSEMINATED, MINERALIZED RHYOLITE, FLUX, ETC.)

▨ MINERALIZED RHYOLITE AT 100'-LEVEL

▨ SULPHIDE-MINERALIZATION AT 100'-LEVEL

300 — EQUIPOTENTIAL-CURVES OR CONTOURS OF ELECTRICAL POTENTIALS FIGURES GIVE VALUES IN MILLIVOLTS

0 100 200
SCALE IN FEET

FIG. 3

running north and south. The potentials observed were plotted against these lines of observation, showing peaks over the areas of spontaneous electrical activity. Figure 3 shows the equipotential-curves deduced from the profiles, and compares them with the mineralization subsequently discovered. The country rock is rhyolite and andesite. The mineralization designated as flux refers to rhyolite heavily impregnated with pyrite and averaging around 0.15 ounce per ton of gold, as distinct from that portion of the sulphide body (not ore) which is practically massive pyrite and contains some little chalcopyrite.

Incidentally, it may be interesting to observe at this point that certain anthracite deposits also produce these spontaneous currents [3, 6, 7]. As a consequence of this, it becomes possible to locate and trace beds of anthracite coal where the truncated edges of the beds are concealed by surface-detritus. It readily becomes evident that with this application we are verging into stratigraphical studies and investigations of folding and faulting.

A step further in this direction can be achieved where the geological series embraces graphite-bearing rocks. Graphite, being a metallic conductor, also generates spontaneous polarization-currents. As a result, horizons of graphitic schists, whose outcrops are concealed by overburden, can readily be traced by the electrical currents they generate. A survey of this type was carried out by the Schlumberger organization in the Belgian Congo. A graphitic horizon was readily followed, serving to outline the Luushia anticline in Katanga. The primary purpose was admittedly not to obtain tectonic information, but to guide some further mining exploration directed towards discovering oxide- and carbonate-ores of copper. Because of the known stratigraphic relationship of the series carrying these ores to the graphitic horizon, the tracing of the latter provided an indirect attack to the exploration-problem [5]. Here we have an excellent example of the application of prospecting methods to the delineation of structural features, which, incidentally, are of importance to the mining engineer.

There is another type of electric current unceasingly flowing in the ground whose origin is quite different from that of spontaneous polarization. It occurs on a broader, in fact a world-wide scale, but nevertheless falls in the classification of electrical activity natural to the Earth itself. I refer, of course, to ordinary telluric currents, which have long been an object of study by geophysicists. It has remained, however, for Marcel Schlumberger and H. G. Doll, brother and son-in-law, respectively, of the late Conrad Schlumberger, to utilize these telluric currents for structural studies [8]. The technique developed by these experimenters for putting telluric currents to work depends on observing their manner of variation from place to place as compared to their simultaneous variations at a base-station. Solar influence, at least in part, probably generates the currents, but their variations are symptomatic of terrestrial structures. Like the flow of water in a stream-bed, these earth-currents go around or over geological formations of high electrical resistance. The characteristics of this flow can be deduced from observations at the surface of variations in the telluric field, providing the geophysicist with a means of depicting major irregularities in the deep-lying formations. Thus a new tool is offered for the discovery of concealed intrusions of igneous rock, of salt-domes, and of taking a qualitative picture of the contours of basement igneous complexes.

The phenomena of natural electric currents, whether of spontaneous polarization or telluric origin, are easy to comprehend and simple to apply. Admittedly, they do not have the wide scope of electrical resistivity-methods, yet nevertheless it is evident that under certain circumstances they can be of very real help in the study of structure and stratigraphy. The utilization of telluric currents for subsurface studies is a new technique, and one whose further development is worth watching. The geophysicists concerned with the architecture of the continental frameworks may well find herein new methods of attack on their problems.

An important limitation on the utilization of spontaneous polarization-currents is the restricted depth to which the technique can be applied. We normally consider that a metallically conductive body, such as of sulphides, graphite, or anthracite, must have its apex within 200 or 300 feet of the surface to be detected by the currents it generates. Evidently this restriction as to the depth of his investigations is due in large part to the fact that the geophysicist can not change the energy available for study to suit the scope of his exploration. We find the same kind of limitation applying to magnetic studies and to gravitational ones. These might be called static methods, to differentiate them from electrical resistivity and seismic methods, to which the term dynamic might be applied.

If the geophysicist takes into the field a generator to provide him with a current to be passed through the ground, he can then suit the energy applied in the area of investigation to the scale of the problem he is studying. Under these circumstances he is endowed with the power of deeper penetration and of controlling his depth of investigation. For the initiation of

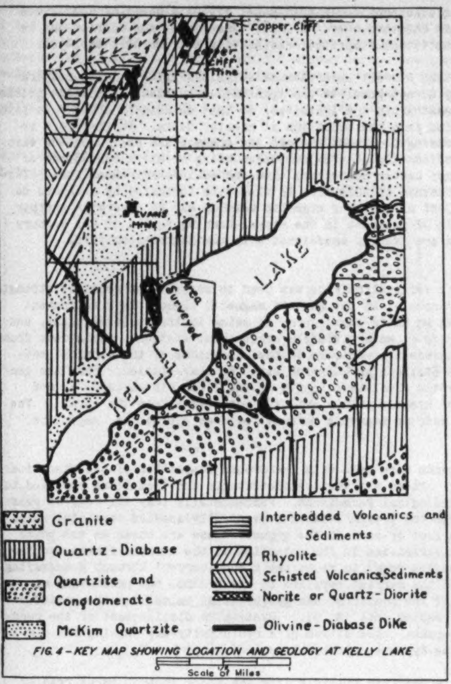


FIG. 4 - KEY MAP SHOWING LOCATION AND GEOLOGY AT KELLY LAKE

electrical investigation of earth-structure, great credit should go to Conrad Schlumberger [3], Frank Wenner [9], Burton McCollum [10], Hans Lundberg [11a], O. H. Gish and W. J. Rooney [12], Harry Conklin [13], Karl Sundberg [11b], Daniel G. Chilson [14], and J. J. Jakosky [15].

The application of electrical resistivity-methods as a technique for structural studies is found in some of the earliest work conducted by Conrad Schlumberger in France. For the purpose of this discussion, however, I shall ignore the chronology and take up first the more direct applications of such methods for determining the presence or absence of mineral formations. The importance of proving the absence of mineralization is sometimes overlooked, but the elimination of barren areas is just as necessary in reducing the cost of exploration as is the delineation of mineralized ones. This conception as applied to oil-prospecting has been emphasized by E. E. Rosaire [16], who says ".... that the major portion of the discovery cost was the 'not-finding' cost, the recognition of unfavorable areas." This same condition obtains in the mining industry, and it therefore becomes important to reduce the "not-finding" costs, the expense of eliminating barren areas from further investigation. As one illustration of this point let me cite a survey carried out under difficult conditions, for the purpose of determining the presence or absence of sulphide mineralization beneath Kelley Lake, near Copper Cliff, in the great nickel-producing area around Sudbury, Ontario.

Omitting details about the geological formations, the situation is as follows. A mantle of glacial drift covers the area, but enough outcrops are visible to indicate fairly well the general nature and strike of the bedrock formations. Their strike is in a northeast direction, the longer axis of Kelley Lake lying parallel thereto; the rocks are lavas and sediments of pre-Cambrian age, tilted to a nearly vertical position, and intruded by various igneous masses and dikes. The north shore of Kelley Lake consists of quartzites and slates intruded by quartz diabase. The south shore is formed of Ramsay Lake conglomerate and Mississagi quartzite. Only a small portion of the Ramsay Lake formation shows towards the southwest, as to the northeast it passes beneath the Lake (Fig. 4).

The above formations have been cut through by two systems of dikes. One system, consisting of two olivine diabase dikes, is of no commercial importance. The other, a quartz diorite one, is intimately related to the norite and micro-pegmatite known as the nickel-bearing eruptive, which has been the source of the nickel ore mined in this district. The Copper Cliff Mine is located close to an outcrop of this dike, the No. 1 Mine is near another, and the Evans Mine is close to a third. It was hoped that the intersection of this dike with the Ramsay Lake conglomerate beneath the bed of Kelley Lake would form a favorable locus for deposition of ore. A reason for this hope is the belief that the Ramsay Lake conglomerate, instead of being a true sedimentary one, may actually be a "crush conglomerate" or so-called "Frood breccia," which has been observed to be a favorable host for sulphide mineralization [17]. The finding of some scattered sulphides in the dike-outcrop on the shore of the Lake strengthened this hope.

These scattered sulphides in the dike provided a test-zone, giving a basis of comparison for evaluating the geophysical results obtained over the Lake. The survey was carried out in mid-winter, working on the ice. Magnetic and electrical resistivity methods were employed.

The spontaneous-polarization method was not used because sulphides lying beneath comparatively stagnant lake water apparently do not generate the spontaneous currents. It seems probable that the processes of oxidation and weathering are inhibited, so that no acid is created to form an electrolyte of different composition from the solutions at greater depth. It therefore becomes necessary to use a method of passing a current through the ground, and observing the electrical resistivities of the subjacent formations. The sulphides being metallic conductors of electricity are many thousands of times better conductors than the wall-rocks, whose conductivities are purely electrolytic. The presence of sulphides is therefore indicated by a marked decrease of ground-resistance. The object of applying magnetic methods was to determine whether or not pyrrhotite is present. This is of interest in the nickel-bearing region of the Sudbury district, since the nickel ores there are usually associated with the magnetic sulphide pyrrhotite.

In the magnetic survey an Askania vertical balance was used to measure the relative strength from place to place of the vertical component of the Earth's magnetic field. This instrument consists of a magnetic needle, mounted on knife-edges so as to swing in the vertical plane, and adjusted to lie in a horizontal position at an arbitrarily chosen base-station. Deviations from this horizontal position at other stations are a measure of the variations of the vertical component of the magnetic field at those stations as compared with the base-station. Thus the geophysicist does not attempt to measure the absolute strength of the field, in which he is not fundamentally interested, but concerns himself solely with its variations from the normal. The field is stronger, of course, over a body of magnetic material such as pyrrhotite, magnetite, and basic rocks.

In the electrical work, measurements were made with the Ground Comparator of the electrical resistivities of the underlying rocks. There are various instruments and techniques employed to measure electrical resistivities of geological formations. Fundamentally they all rely on passing a current of known strength through the ground between conveniently located contacts, which usually consist of iron pegs driven a foot or more in the ground; these are known as the power pegs. Readings are then taken of the variations in the potential of the current flowing in the ground, by using similar contacts (reading pegs) to shunt the ground-current through a measuring apparatus. From the known amperage of the current supplied to the ground, the potentials observed and the spatial relationships of the contacts, the geophysicist calculates the resistivity of the formations underlying the reading pegs [3, 9]. Systematic displacement of the reading pegs in the area to be surveyed permits construction of a resistivity-map showing the disposition of those formations possessing typical resistivities [18].

The Ground Comparator technique is modified slightly from the above in that three reading pegs are used, and instead of measuring the absolute resistivities the instrument records the ratio of ground-resistance between the front and middle pegs to that between the middle and rear pegs. It thus records the variations of ground-resistance from place to place rather than its absolute values [19].

For most of this survey the reading electrodes of the Ground Comparator were placed 100 feet apart and moved 100 feet at a time. The same interval was used for the magnetic stations. Near the outcrop of the dike, however, 50-foot intervals were employed. The profiles along which the measurements were made were oriented to cut across the quartz diorite dike, since it was expected that any mineralization present would occur in or close to it. The results are shown in Figure 5.

As far as any possible mineralization is concerned, both the electrical and the magnetic effects observed near the middle of Kelley Lake were weak, and comparable in strength to those registered on the dike-outcrop where only scattered sulphides were visible, indicating that they could be caused by only very weak concentrations of sulphides of unimportant extent. On this basis no further work was recommended in that area.

By comparing the cost of this survey with the expense of obtaining the same information by drilling, it becomes apparent that a very important reduction was effected in the "not finding" cost. To have drilled the length of this dike from the ice could easily have necessitated an expenditure of $10,000 or more, whereas the geophysical survey cost only about $2000.

The structural information obtained during the course of this survey turned out to be of no commercial interest, but will serve to emphasize the fact that the exploration geophysicist nevertheless obtains information of importance to the structural geologist. In brief, the course of the quartz diorite dike was traced as it passed beneath the waters of Kelley Lake; the sinuosities of the eastern olivine diabase dike also showed up clearly on the geophysical results; the western dike of olivine diabase was not traced across the Lake, but its emplacement near the south shore was clearly shown; and the probable contacts between the McKim formation and the Ramsay Lake conglomerate, and between this conglomerate and the Mississagi quartzite, were tentatively traced even though completely concealed beneath the Lake waters.

A case in which the geophysical delineation of structure resulted in the discovery of an important ore-body, however, is provided by the survey of the Broulan Porcupine Mines, Ltd., in Whitney Township, northern Ontario.

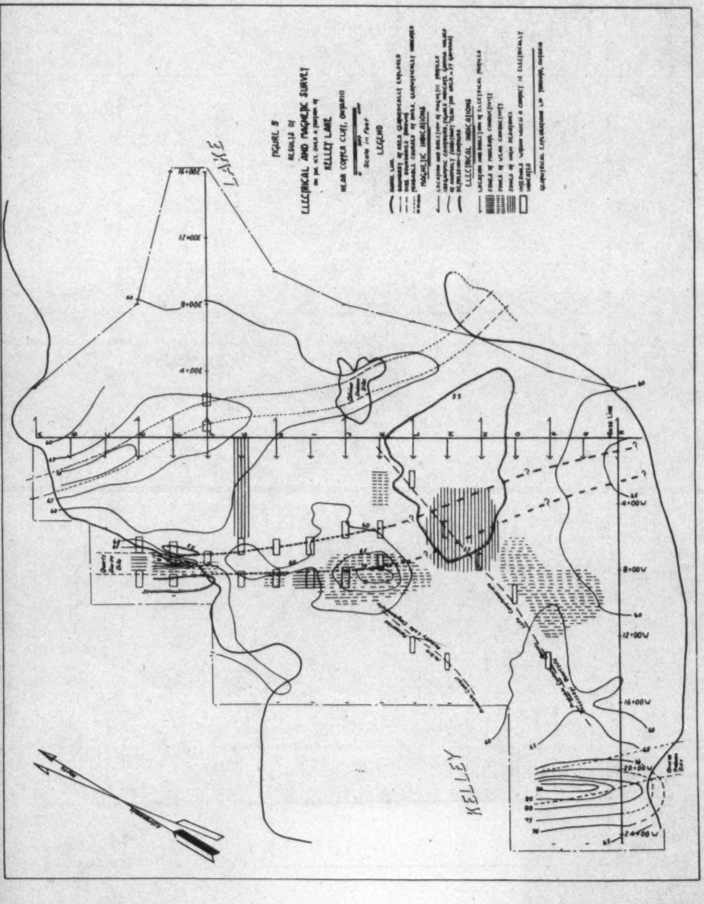


FIGURE 5

RESULTS OF ELECTRICAL AND MAGNETIC SURVEY

KELLEY LAKE

NEAR COPPER CLIFF, ONTARIO

Scale in Feet
LEGEND
MAGNETIC INDICATIONS
ELECTRICAL INDICATIONS
LAKE
KELLEY
16+00E
12+00E
8+00E
4+00E
Base Line
4+00W
8+00W
12+00W
16+00W
20+00W
24+00W

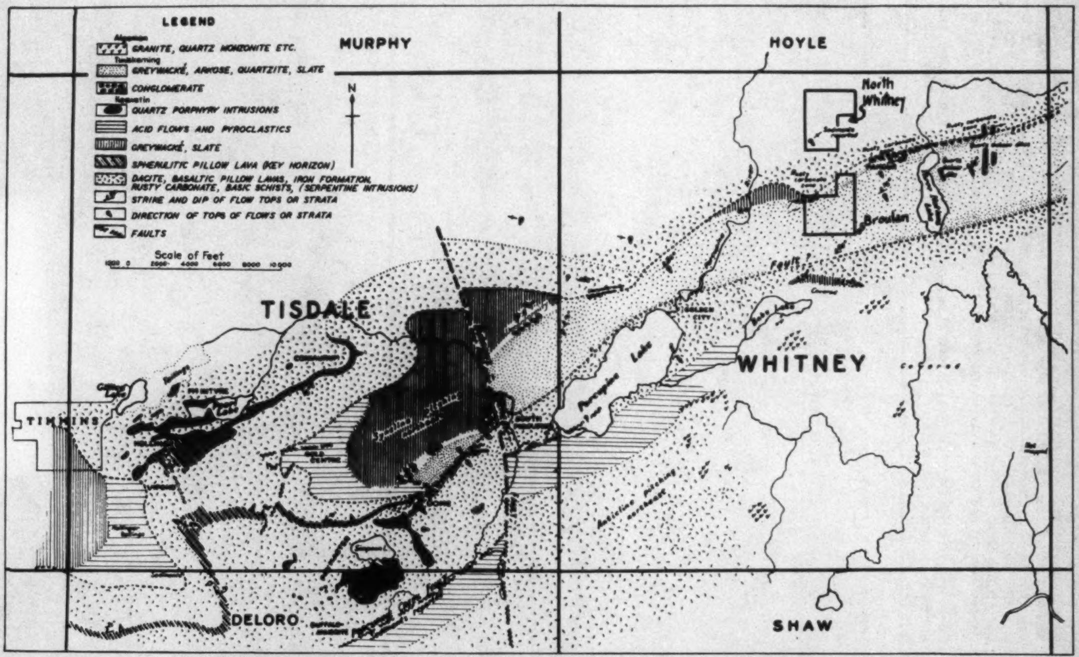

LEGEND
Algoman
GRANITE, QUARTZ MONZONITE ETC.
Timiskaming
GREYWACKÉ, ARKOSE, QUARTZITE, SLATE
CONGLOMERATE
Keewatin
QUARTZ PORPHYRY INTRUSIONS
ACID FLOWS AND PYROCLASTICS
GREYWACKÉ, SLATE
SPHERULITIC PILLOW LAVA (KEY HORIZON)
DACITE, BASALTIC PILLOW LAVAS, IRON FORMATION, RUSTY CARBONATE, BASIC SCHISTS, (SERPENTINE INTRUSIONS)
STRIKE AND DIP OF FLOW TOPS OR STRATA
DIRECTION OF TOPS OF FLOWS OR STRATA
FAULTS
Scale of Feet
1000 0 2000 4000 6000 8000 10000
N
MURPHY
HOYLE
TISDALE
WHITNEY
TIMMINS
DELORO
SHAW
North Whitney
Broulan
Fault ?
Porcupine Lake

FIG. 6—GENERALIZED GEOLOGICAL MAP OF CENTRAL PART OF PORCUPINE AREA (TOWNSHIPS ARE SIX MILES SQUARE)

This property is situated in the Porcupine district of Ontario, where such famous mines as the Hollinger, the McIntyre, the Dome, the Pamour, etc., are found. The formations are pre-Cambrian in age, and consist of Keewatin lavas overlain by Keewatin and Timiskaming sediments. These have been folded in a great syncline, with the sediments occupying the trough, Figure 6. This syncline strikes in a northeasterly direction, the dip of the formations being steeply to the north. The contact of the sediments with the lavas along the north limb of the syncline has been found to be a favorable locus for ore-deposition as, for example, at the adjoining Pamour Porcupine Mine to the east, and the Hallnor Mine to the northwest of the property under consideration.

The tasks set the geophysicists were: (1) To locate the lava-sediment contact; (2) to indicate the general trend of the structure in the sediments; (3) to try to locate faults; and (4) to discover silicified zones.

Three 40-acre claims were surveyed by Ground Comparator resistivity and magnetic methods. The overburden, consisting of glacial drift, varies from 15 to 90 feet in depth, and, while some scattered outcrops occur on nearby claims, none were found on the three surveyed.

It was anticipated that the lavas would show a stronger magnetic effect than the sediments, and thus permit the delineation of the contact between them. As a matter of fact, the two formations proved to have practically the same magnetic reaction, so that the tracing of this contact was difficult. There was one place a few feet north of the northwest corner of the Broulan property where the position of the contact had been established by drilling. The magnetic profile at this place showed a distinctive pattern of peaks and valleys with which profiles farther east could be correlated. On this basis the contact was located for a short distance, north of the Broulan boundary, and about parallel thereto. Where subsequently tested by two drill-holes it was found within 30 to 70 feet of the predicted location.

The sediments underlying the Broulan claims are composed of such thinly banded greywackes and slates that no given horizon was thick enough to exert a distinctive and persistent effect on the resistivity-ratios. Under these circumstances the best that could be done was to correlate groups of resistivity-ratio patterns from one profile to the next, on the assumption that successive similar patterns corresponded to a given assemblage of strata. Since the sedimentary bands vary along their strike, it is inevitable that the given assemblage will change its character, and thus produce a shifting and merging of resistivity-ratio patterns. These phenomena are indicated by the cross-hatching in Figure 7, which shows a predominantly east-west strike for the underlying beds. Further study of these patterns showed two regions, one at the west near Profile C and the other between Profiles G and K, where a correlation could not be made between successive profiles. From this it was deduced that the strata had probably been dislocated by faulting or sharp folding in these two areas. Drilling subsequently revealed faulting in both regions.

High magnetic readings in the western part of the property indicated the presence of more basic rocks, and from the known geology of the area it was thought they would probably be serpentine. The deeper drill-holes later put down encountered a serpentinised schist beneath the magnetic highs.

From a commercial point of view, however, the really important result of this survey was to indicate a highly resistant band near the northern boundary of the western claim. This high resistance was believed to be due to the presence of a silicified zone, and since the gold in this region is commonly associated with silicification, the area became one of potential importance. When the drills were moved in to test it, they encountered an ore-body consisting of a highly silicified zone in the sediments, shot through with many veins of quartz, and carrying good gold values [20]. Its outline compared well with the predicted one, and the property is now being developed by shaft and levels. A recent report in the Northern Miner stated that over half a million tons of $7.00 ore had been outlined in the drilling campaign. Also, recent investigation is reported to have disclosed the possibility of a second ore-zone some 300 feet south of the base-line in a second resistant zone. This geophysical survey cost in the neighborhood of $3500.

Although the prime objective of the survey was to locate a silicified formation, no small amount of structural information was also obtained. In fact, strictly speaking, the location of silicified zones is a structural problem, and should always be considered as such and nothing more. The mere location of a silicified body or quartz vein does not prove the presence of gold ore, but merely that a structure or formation exists in which gold values might occur.

Another survey in the same district will serve to illustrate a further broadening of the application of geophysics to making structural studies for the assistance of the engineer charged with developing a mining property.

Four claims of the North Whitney Mines, Ltd., located in the same (Whitney) township, about half a mile north of the Broulan, were surveyed in mid-winter by magnetic, Ground Comparator resistivity, and spontaneous polarization-methods. The geophysicists were asked (1) to trace the extensions of a known quartz-vein, (2) to trace a shear-zone known to occur near the northwest corner of the area being studied, (3) to locate and trace the nose of a supposed anticlinal fold, presumably marked by a contact between sediments and lavas, in the southern part of the property. It was anticipated that this contact would provide a favorable region for ore-deposition, especially where bent around the nose of the fold. The axis of the fold was thought to have an east-west strike, and the nose was believed to lie in the southern part of the North Whitney property. In order to complete the geophysical picture, permission was obtained to overlap the survey on adjoining properties.

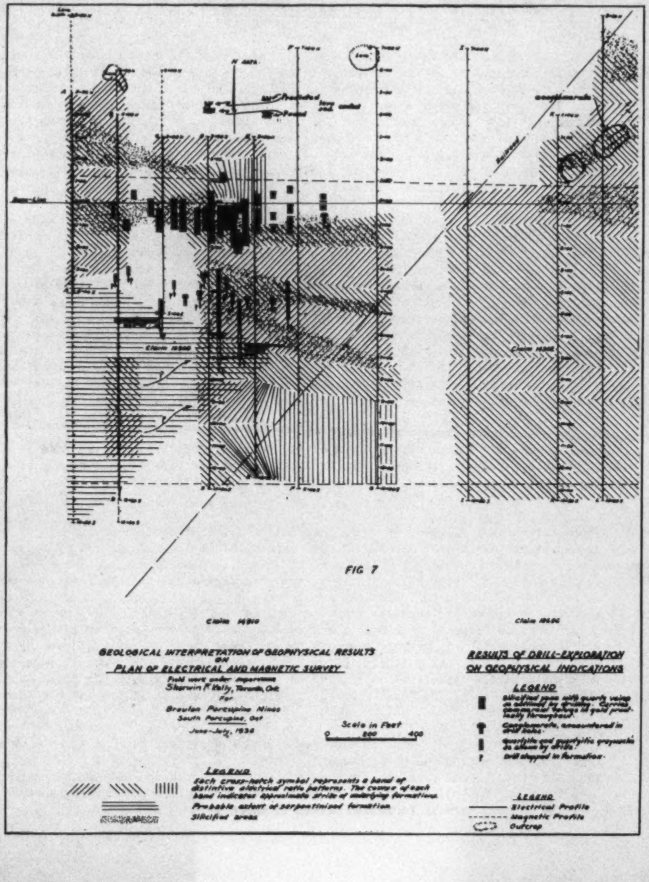
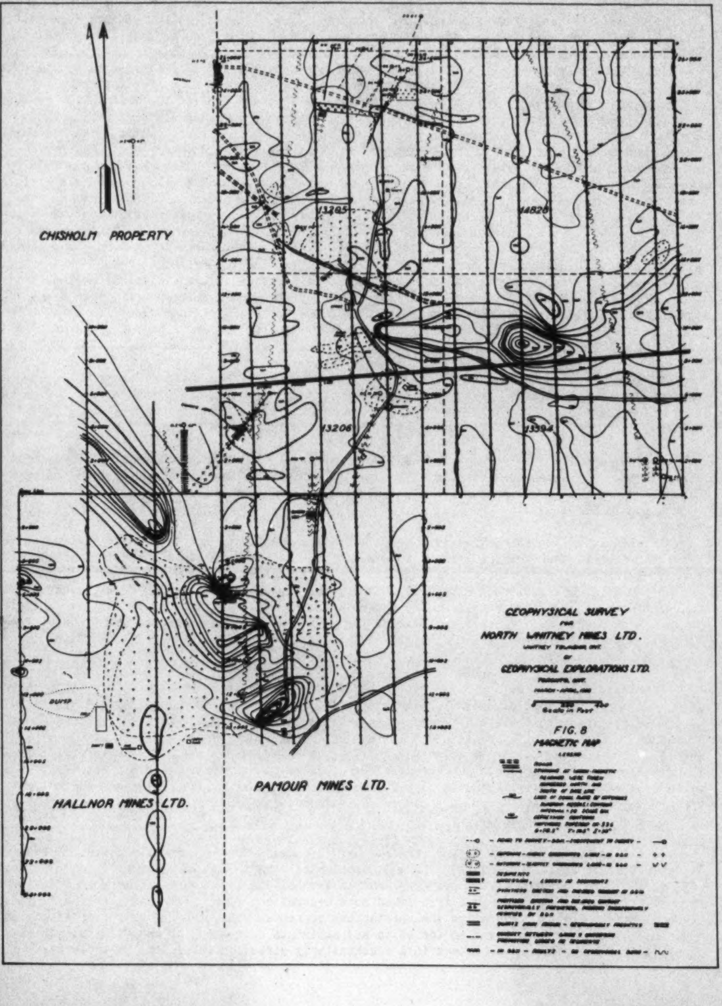

Base-Line
Conglomerate
Claim 14900
Claim 14906
Claim 14910
Claim 18686
GEOLOGICAL INTERPRETATION OF GEOPHYSICAL RESULTS
ON
PLAN OF ELECTRICAL AND MAGNETIC SURVEY
Field work under supervision
Sherwin F. Kelly, Toronto, Ont.
For
Broulan Porcupine Mines
South Porcupine, Ont
June-July, 1936
Scale in Feet
0 200 400
RESULTS OF DRILL-EXPLORATION
ON GEOPHYSICAL INDICATIONS
LEGEND
Silicified zone with quartz veins as outlined by drilling. Carries commercial values of gold practically throughout.
Conglomerate, encountered in drill holes.
Quartzite and quartzitic greywacke as shown by drills.
Drill stopped in formation.
LEGEND
Each cross-hatch symbol represents a band of distinctive electrical ratio patterns. The course of each band indicates approximate strike of underlying formations.
Probable extent of serpentinized formation
Silicified areas
LEGEND
Electrical Profile
Magnetic Profile
Outcrop

FIG 7

For the magnetic survey a Hotchkiss Superdip was employed. The Superdip consists of a magnetic needle free to swing in the vertical plane, and carrying a non-magnetic counterarm and counterweight. The arm and weight are used to balance the moment of gravity, and can be adjusted by the operator to endow the instrument with any sensitivity desired for the survey in hand. The needle is clamped in a vertical position, and when released swings in an arc whose magnitude is a measure of the total strength of the magnetic field at that point. The reading is made by noting the maximum number of degrees swing of the needle when first released. The readings thus


CHISHOLM PROPERTY
13285
14826
13206
13394
HALLNOR MINES LTD.
PAMOUR MINES LTD.
DUMP
GEOPHYSICAL SURVEY
FOR
NORTH WHITNEY MINES LTD.
BY
GEOPHYSICAL EXPLORATIONS LTD.
Scale in Feet
FIG. 8
MAGNETIC MAP
LEGEND

recorded on successive profiles may be combined to form a contour-map of the relative magnetic intensities in the area studied. Figure 8 shows the magnetic map thus drawn up on the North Whitney Mines property.

The fact that a lava-sediment contact was expected to mark the anticlinal fold in the southwestern part of the property led to the expectation that this structural feature could be outlined magnetically. The feature of the magnetic results, upon which was based the placing of the lava-sediment contact in the southwest, does not show on the contour-map but was taken from the profiles. It consisted of a small but sharp increase in the magnetic readings near certain stations when proceeding northwards along Profiles A to E. This phenomenon occurred near station 6 + 00N on Profile A, where the contact was thought probably to occur. The presumed contact was then tentatively drawn through the other stations showing a similar change in magnetic intensities (see Fig. 8). This resulted in showing a pronounced southeasterly strike for the contact, instead of the anticipated east-west one, so that the nose of the fold would lie south of its expected position. Since the magnetic indication was admittedly a dubious one, of so slight a magnitude as to have been probably overlooked if not previously anticipated, it was deemed advisable to get further confirmation on the strike thus indicated. This was provided by the observations on the neighboring Hallnor and Pamour properties, which revealed a series of pronounced magnetic highs with a trend definitely parallel to that of the questionable contact-indication. With this additional support the contact was then drawn in as shown on the map. Two drill-holes, NW-14 and NW-17, were put down and checked the geophysical predictions. Examination of the drill-cores, however, showed that a part of the formation cut was of uncertain classification. In the main, carbonated lavas were intersected, but there was a band about 100 feet wide of rock so badly altered that even a microscopic examination failed to reveal whether it was of sedimentary or igneous origin. It was of definitely different lithologic nature than the rocks on either side of it, however, and was evidently the formation responsible for producing the magnetic indication which was interpreted as a manifestation of the sought-for lava-sediment contact. Both drill-holes intersected narrow quartz-veins in this band of rock, one of them assaying $27 to the ton in gold.

The pronounced band of magnetic highs with a southeast strike cutting across the Hallnor and into the Pamour properties, gives the impression of possibly being due to the presence of a basic flow which has been folded into an anticline plunging to the southeast, although an alternative explanation could ascribe it to the truncated edge of a thick flow of basic lava.

Another magnetic high trends east and west across Claim 13594, overlapping part way onto Claim 13206. The appearance of this high suggests a tightly folded syncline with an eastward plunge. There are no outcrops with which to correlate this indication, but it is presumably due to a basic lava.

It is interesting to observe that the electrical resistivity indications of the quartz-vein (Fig. 9) terminate against the nose of this magnetic high. A possible hypothesis is that the formation responsible for the higher magnetic readings is a soft one, which by shearing absorbed the differential movement responsible for opening the fissure in the harder rocks, subsequently quartz-filled, so that the vein does not extend into the softer material. In this event the formation which did not fracture may have served as a confining wall against which the mineralizing solutions rose and from whence they spread to the northwest, filling the fissure and permeating the wall-rocks.

This hypothesis is strengthened by the spontaneous polarization-readings (Fig. 10), which show weak currents indicative of disseminated pyritic mineralization to the north (hanging wall) of the vein, except in the vicinity of the nose of the magnetic high where the readings indicate sulphides in the foot-wall to the south as well. A greater spreading of the solutions would naturally be expected in the immediate vicinity of the dam against which they were confined. Since these solutions presumably introduced the gold, this area immediately becomes one of possible commercial interest, but this part of the vein has not as yet been tested. Where the known portion of the vein has been explored, sulphide disseminations and veinlets have been encountered in the hanging wall.

In the northwestern part of the area surveyed, on Claim 13205, a certain amount of spontaneous polarization-activity is noted. This is associated with a shear-zone encountered in a drill-hole at the west boundary of the property, and in several old holes some thousand feet east thereof. This is more properly a brecciated zone mineralized with pyrite and graphite, the substances responsible for generating the spontaneous currents. This sheared and brecciated zone marks the contact between lavas on the south and sediments on the north, and prior to the geophysical work was believed to extend in a southeasterly direction across the North Whitney property. The western portion, mineralized with pyrite and graphite, is well indicated by the natural electrical currents, but the zone as a whole is conductive, even to the east where probably not so well mineralized, and its location is therefore more clearly depicted by the electrical resistivity-measurements. In Figure 9 it will be observed as a conductive band extending east and west across the northern part of the property, with certain minor dislocations north and south probably due to some transverse faulting. Some of these faults cut the quartz-vein farther south and apparently shift its western extension to the north some 150 feet.

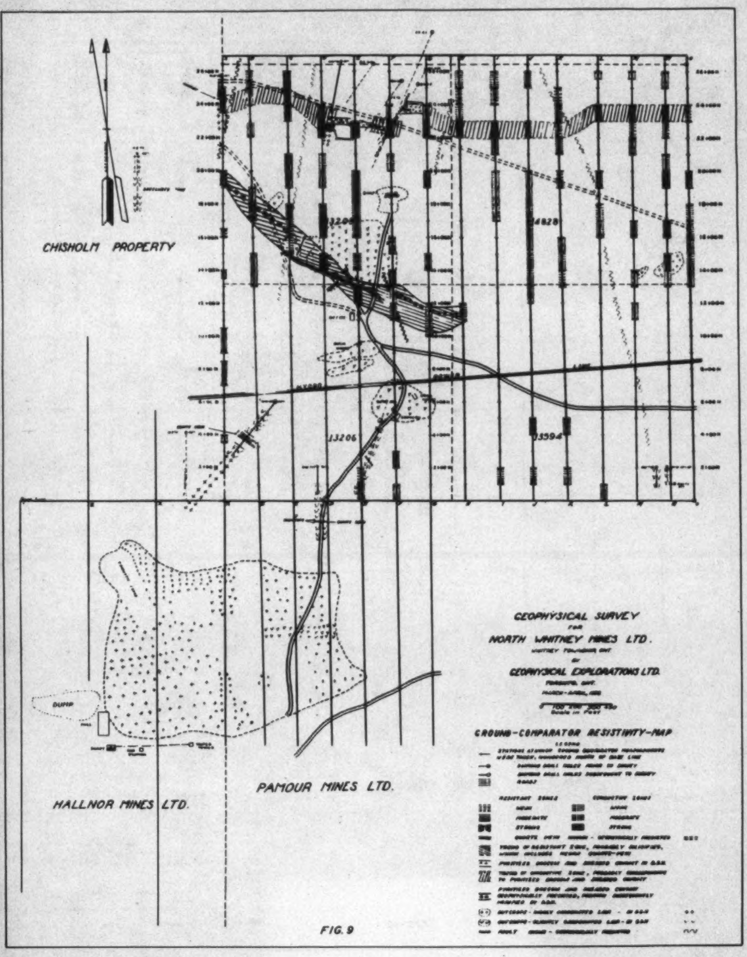

CHISHOLM PROPERTY
13204
14828
13206
13594
DUMP
PAMOUR MINES LTD.
HALLNOR MINES LTD.
GEOPHYSICAL SURVEY
FOR
NORTH WHITNEY MINES LTD.
BY
GEOPHYSICAL EXPLORATIONS LTD.
0 100 200 300 400
Scale in Feet
GROUND-COMPARATOR RESISTIVITY-MAP
LEGEND
RESISTANT ZONES
CONDUCTIVE ZONES

FIG. 9

These geophysical deductions are summarized on Figure 11, and may be briefly recapitulated as follows. A lithologic contact between lavas and a band of uncertain classification was shown to have a southeasterly strike across the southwesterly corner of the North Whitney claims. This trend is paralleled to the southwest by a basic formation, which is probably a lava-flow bent into an anticlinal fold plunging to the southeast. This anticline is succeeded to the northeast by another basic formation which seems to have been folded into a syncline with an easterly plunge. The quartz-vein known as the Keora Vein, which has produced some gold, apparently abuts against the nose of this basic rock and does not extend through it. The quartz-vein has been cut by at

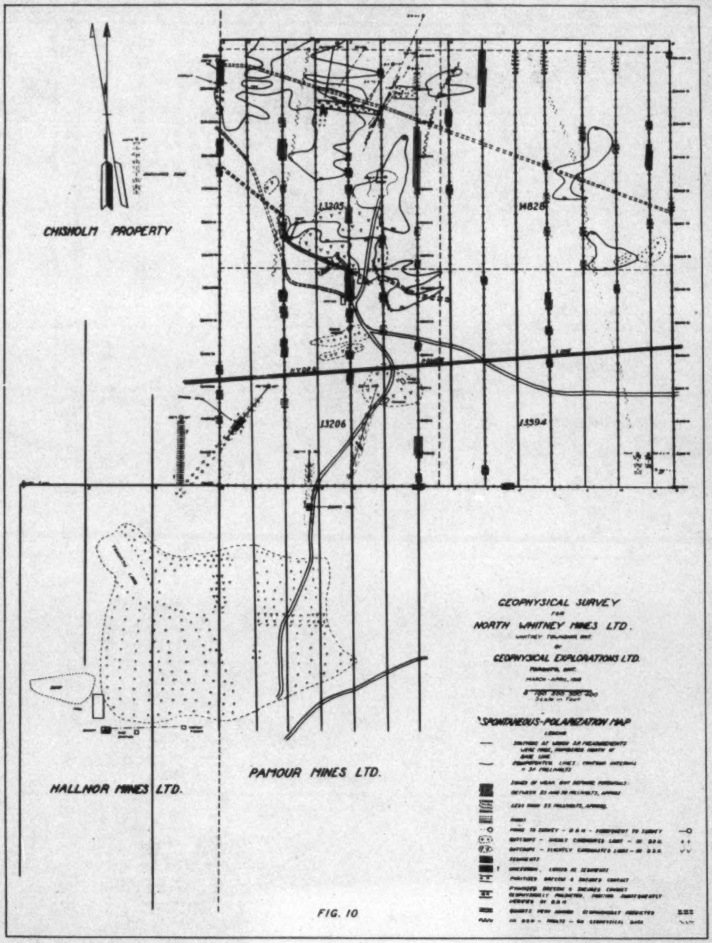

CHISHOLM PROPERTY
13205
14828
KEORA
LINE
13206
13394
HALLNOR MINES LTD.
PAMOUR MINES LTD.
GEOPHYSICAL SURVEY
FOR
NORTH WHITNEY MINES LTD.
BY
GEOPHYSICAL EXPLORATIONS LTD.
0 100 200 300 400
Scale in Feet
SPONTANEOUS-POLARIZATION MAP

FIG. 10

least two faults, in which the southeasterly and northwesterly extensions have both been moved north. These faults have also dislocated a sheared and brecciated zone, which marks the contact between the lavas underlying most of the area surveyed, and sediments which succeed them to the north. Thus an anticlinal fold in the south seems to be followed by a synclinal fold towards the middle of the area, with the north limb of the supposed syncline cut by a strike-fault which brings the lavas of that limb into contact with sediments lying to the north.

The hypotheses as to the structure of the rocks in this area are admittedly no more than

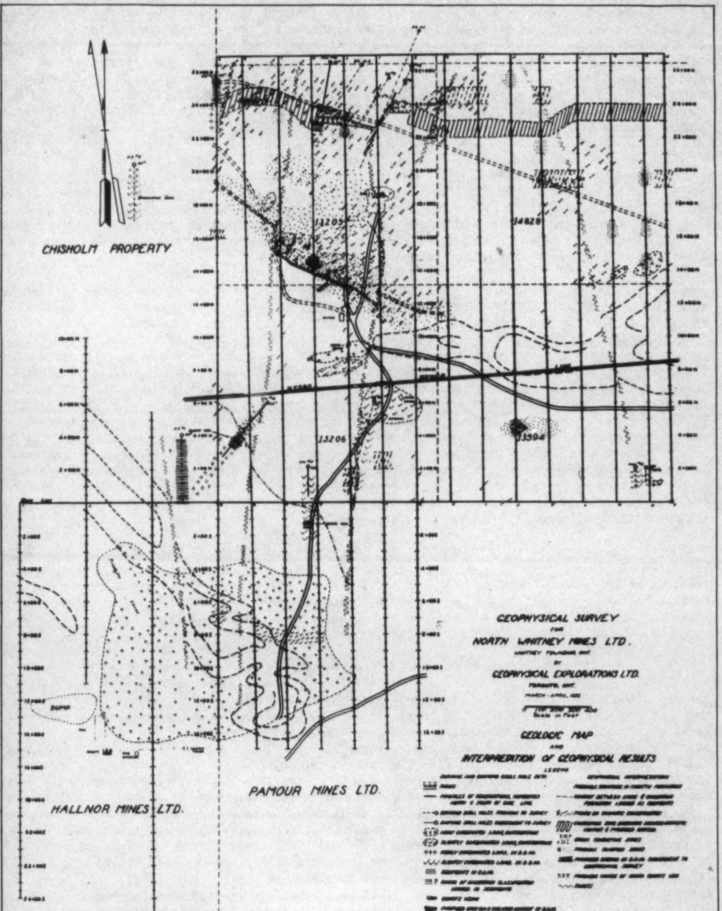

CHISHOLM PROPERTY
13205
14828
13206
13594
HALLNOR MINES LTD.
PAMOUR MINES LTD.
DUMP
GEOPHYSICAL SURVEY
FOR
NORTH WHITNEY MINES LTD.
WHITNEY TOWNSHIP, ONT.
BY
GEOPHYSICAL EXPLORATIONS LTD.
TORONTO, ONT.
MARCH - APRIL, 1938
0 100 200 300 400
Scale in Feet
GEOLOGIC MAP
AND
INTERPRETATION OF GEOPHYSICAL RESULTS
LEGEND

FIG. 11

hypotheses, but to some extent are of help in orienting an exploration-program. They have already been partially justified by the fact that drilling based upon them has verified the position of the contact in the southwestern part of the property, and has shown that gold deposition has occurred there. The position of the shear zone in the north has also been verified, but as yet it has not proven to be of commercial interest. Based on these geophysical deductions, an extension of the exploration of the known vein has been recommended, but this has not yet been tested.

In spite of having extended the geophysical work beyond the area of immediate interest, it is quite evident that the structural deductions are actually based on somewhat skimpy evidence. If geological structures are to be adequately delineated by geophysical methods, the survey can not logically be confined to a small region but must embrace a sufficiently large area for the geophysicist to get a perspective of the picture as a whole. Thus he will be able to correct any misconceptions that may arise from attempting to interpret geophysical readings which may be due to purely local anomalies. In other words, he must not confine himself to the microscope, but should bring the telescope into play as well.

In the previous discussion of geophysical surveys I have concentrated on the microscopic phase of the work in order to describe the procedures whereby the applied geophysicist arrives at his conclusions regarding the possible presence of promising mineral bodies, or the probable structure of the underlying rock-formations. With this as a background I shall proceed to a very brief consideration of some outstanding surveys in which the geophysicists have operated on a larger scale, and have so brought their detailed results together into a comprehensive picture giving a perspective of regional structure.

In the same Porcupine district of northern Ontario from which two of the preceding examples were drawn, an extensive survey by Hans Lundberg, Ltd., was recently carried out for the purpose of verifying a structural hypothesis. This hypothesis, based on some surface-outcrops and drill-results, postulated the existence of another syncline lying approximately parallel to and five or six miles west of the one already mentioned, in which so many important producing mines of the Porcupine district are located (Fig. 12). It was hoped that if such a syncline existed, similar geological conditions would also obtain, and that new ore-bodies might be found therein. The geophysical survey was carried out in the southeastern part of Godfrey and southwestern part of Mountjoy townships. It involved the study of areas in which the bedrock is concealed by overburden, using magnetic and electrical resistivity-methods for the purpose of mapping the contact between the lavas and the sediments forming the trough of the syncline, revealing areas of drag-folding and shearing, locating intrusions of porphyry, and indicating zones mineralized with conductive sulphides. No reports have been issued as to commercial values encountered in the drilling, but it has been stated that the drill-holes thus far put down have verified the geophysically indicated contacts and conductive zones.

Since the geophysicist is incapable of predicting the presence of ore, it is evident that the value of his work depends fundamentally upon his ability to delineate correctly the major features of geological structure. From this it follows that where structure has exerted an important influence on the locus of ore-deposition, the geophysical investigation of large areas where structural features are not obvious may bring about the eventual discovery of new mining districts, as well as facilitate the extension of known ones.

A highly important extension of a known ore-bearing district was revealed in recent years by an outstanding geophysical study of structure in the Witwatersrand area of South Africa. In the producing area that stretches in a horseshoe shape for 50 miles east and west, the gold-bearing "reefs" of conglomerate come to the surface. To the southwest, however, they pass beneath great thicknesses of horizontal strata, mostly dolomites, which conceal their uptilted edges or sub-outcrops. These overlying dolomites have baffled attempts to locate the western extension of the Rand goldfields for years, as hole after hole failed to tap the rich horizons. In 1930 Rudolph Krahmann conceived the idea of making some trial magnetic surveys in the area of outcropping Witwatersrand series. He thus discovered that certain beds of shales and slates underlying the conglomerates and outcropping north of them, produced typical magnetic reactions, due to their content of magnetite. After a thorough correlation with known occurrences, the magnetic survey was extended over 20 miles to the west, successfully tracing the same beds by means of their magnetic reactions, despite the thousands of feet of overlying rocks (Fig. 13) [21]. With the sub-outcrops of these beds thus located, and their stratigraphic relationships to the gold-bearing horizons being known, geological knowledge of dips, thicknesses of strata, etc., were used to calculate the probable positions of the sought-for reefs. Subsequent drilling on an extensive scale proved the correctness of the geophysical predictions, and opened up a tremendous area for exploitation [22]. At least four shafts are now being sunk on this western

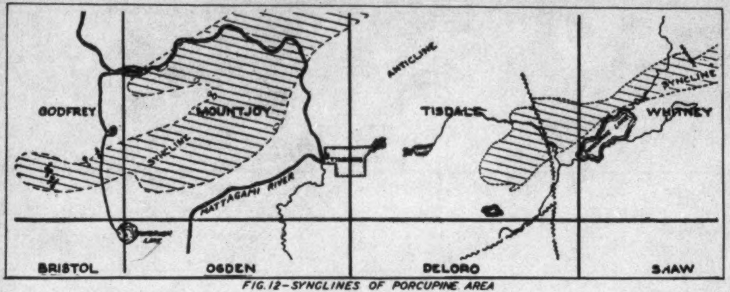

ANTICLINE
SYNCLINE
GODFREY
MOUNTJOY
SYNCLINE
MATTAGAMI RIVER
TISDALE
WHITNEY
BRISTOL
OGDEN
DELORO
SHAW

FIG. 12—SYNCLINES OF PORCUPINE AREA

extension of the Rand Gold-fields, and when exploitation is well under way we are destined to see a pronounced increase in the world's annual production of gold, thanks to this geophysical survey.

In Figure 13 are depicted some of the geophysical results. It shows faults and dikes magnetically located, the predicted positions of the sub-outcrops of magnetic shales, and the calculated location of the main reef conglomerate sub-outcrop. A further extension of the survey west of the Mooi River does not show on this map, but is reported to have revealed a pronounced southerly bend of the formations [22]. This has led to the supposition that the River follows a major fault. That information of this type can be obtained through a thickness of 1000 to 3000 feet of overlying rocks is a striking illustration of the value of geophysical methods in depicting deeply hidden structures, and thus in guiding the exploration engineer to new deposits of rich resources.

Less spectacular, but none the less useful because of its value in reducing the not-finding costs, is one of the earliest electrical surveys for structural information carried out by Conrad Schlumberger's organization. In 1920 a study was made of the May syncline in Normandy for one of the French iron works [18a]. Striking roughly northwest-southeast, the syncline consists of Silurian rocks, including sandstones, shales, and schists, covered by 130 to 260 feet of horizontal Jurassic limestones and clays (Fig. 15). The key to its position and character was provided by a few outcrops where the cover had been eroded away. The interest in this Silurian syncline came from the fact that certain beds of its down-folded sediments carried commercial deposits of iron carbonate (Fig. 14). To the northeast, near the Orne River, the Silurian rocks of the north limb are cut off by a fault which brings pre-Cambrian rocks against them. To the west another fault, south of Fontaine Etoupefor, was also observed, but its relationship to the first-

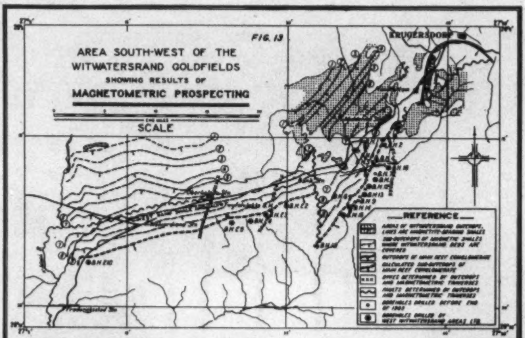

AREA SOUTH-WEST OF THE
WITWATERSRAND GOLDFIELDS
SHOWING RESULTS OF
MAGNETOMETRIC PROSPECTING
SCALE
KRUGERSDORP
REFERENCE
AREAS OF WITWATERSRAND OUTCROPS, LINES ARE MAGNETITE-BEARING SHALES
SUB-OUTCROPS OF MAGNETIC SHALES WHERE WITWATERSRAND BEDS ARE COVERED
OUTCROPS OF MAIN REEF CONGLOMERATE
CALCULATED SUB-OUTCROPS OF MAIN REEF CONGLOMERATE
DYKES DETERMINED BY OUTCROPS AND MAGNETOMETRIC TRAVERSES
FAULTS DETERMINED BY OUTCROPS AND MAGNETOMETRIC TRAVERSES
BOREHOLES DRILLED BEFORE END OF 1933
BOREHOLES DRILLED BY WEST WITWATERSRAND AREAS LTD.

FIG. 13

(AFTER REINECKE, COURTESY AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS)

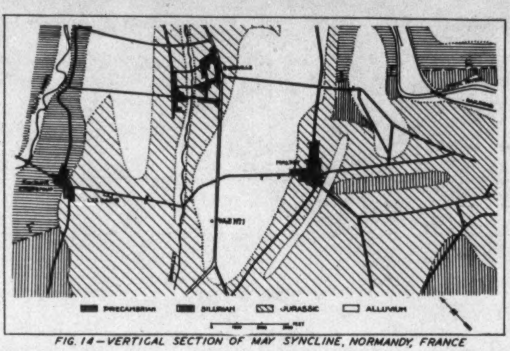

PRECAMBRIAN
SILURIAN
JURASSIC
ALLUVIUM
FEET

FIG. 14—VERTICAL SECTION OF MAY SYNCLINE, NORMANDY, FRANCE

mentioned one was unknown (Fig. 15). On the south limb of the syncline, one drill-hole had encountered the iron formation at a depth of 300 feet.

The problem presented for geophysical solution was to determine the position and extent of the Silurian syncline beneath its mask of Jurassic limestone. It was particularly desirable to know the relationship of the two faults referred to above, and their effect on the north limb of the syncline. These data were required as a guide in further exploration for the iron ore found in the Calymene shales.

Electrical resistivity-profiles were traced perpendicular to the axis of the syncline at intervals over a distance of two miles. The differing resistivities exhibited by the sandstones and shales caused these formations to show up distinctly, as illustrated on the two profiles given in Figure 16. Equipotential-curves were traced, their elongations serving to indicate the direction of stratification of the rocks underlying the horizontal, covering strata. This direction is shown by the double-headed arrows in Figure 16. As the strike of the pre-Cambrian is different from that of the Silurian, the boundary between the two is readily determined by this technique. It resulted in showing that the two faults above-mentioned were actually one, and that it had cut off the north limb of the syncline in the region of Maltot. Because of this abrupt cutting off of the northern limb, the remaining portion was judged not worth exploitation, and the costs of further exploration in that area were thereby saved. The position of the southern limb was proved by subsequent drill-holes, which intersected the iron formation at the predicted locations.

The studies carried out since then by the Schlumberger organization on similar structures

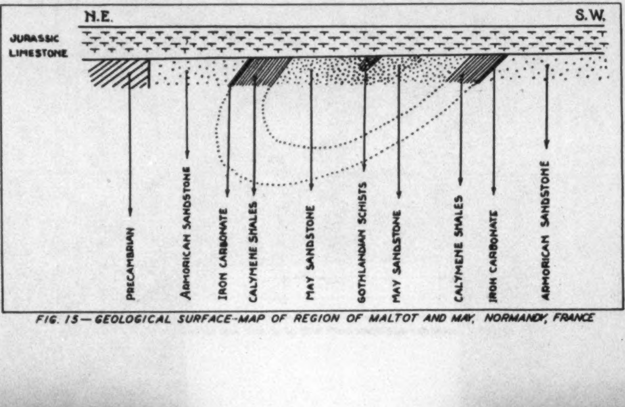

N.E.
S.W.
JURASSIC LIMESTONE
PRECAMBRIAN
ARMORICAN SANDSTONE
IRON CARBONATE
CALYMENE SHALES
MAY SANDSTONE
GOTHLANDIAN SCHISTS
MAY SANDSTONE
CALYMENE SHALES
IRON CARBONATE
ARMORICAN SANDSTONE

FIG. 15—GEOLOGICAL SURFACE-MAP OF REGION OF MALTOT AND MAY, NORMANDY, FRANCE

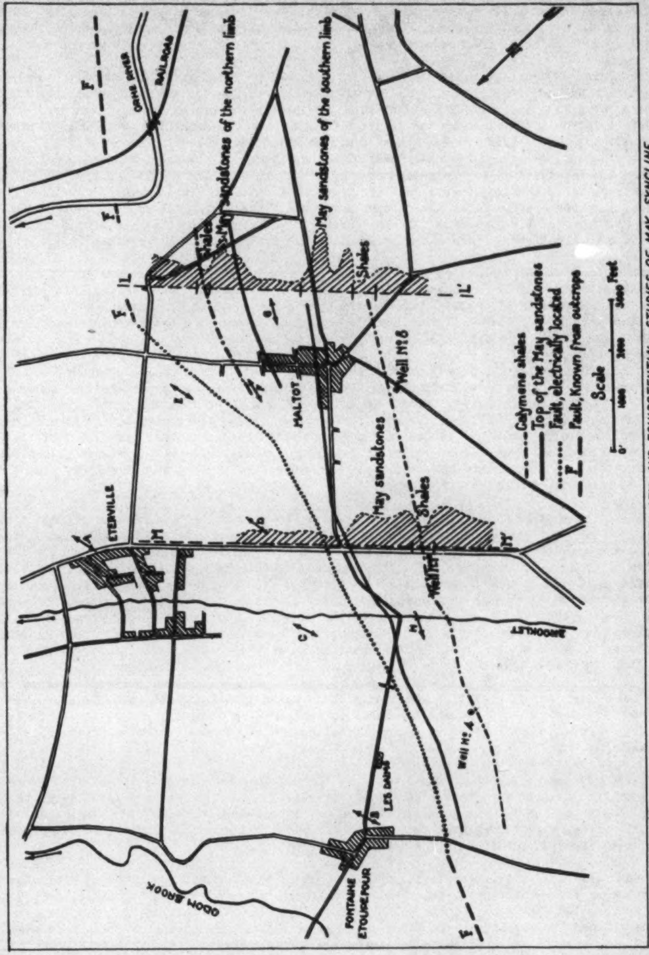

ORNE RIVER
RAILROAD
F
May sandstones of the northern limb
May sandstones of the southern limb
Shales
IL
IL'
ETERVILLE
MALTOT
Well No 8
May sandstones
Shales
M
M'
Well No 7
BROOKLET
Well No 4
LES DAINS
FONTAINE ETOUPEFOUR
ODON BROOK
Calymene shales
Top of the May sandstones
Fault, electrically located
Fault, Known from outcrops
Scale
0 1000 2000 3000 Feet

FIG. 16 — RESULTS OF ELECTRICAL RESISTIVITY—AND EQUIPOTENTIAL—STUDIES OF MAY SYNCLINE

in the iron-mining region of Normandy, have resulted in greatly augmenting the geological knowledge of the tectonics of that area [18b].

In the preceding examples of geophysical prospecting for mineral deposits and to delineate geological structures, we have been concerned principally with its application in the field of metallic resources. The same principles apply, however, with equal force to the search for nonmetallic deposits. One of the most essential for human welfare is that of water, and, as might well be imagined, the attention of the geophysicists has been directed to the solution of problems concerned with its occurrence. Geophysical techniques have been particularly applicable in arid regions such as the western United States, North Africa, Spain, and Palestine, where surface-supplies of water are not adequate and a search must be made for underground sources.

Techniques adapted for the direct location of water-horizons have been described in another paper in this Symposium [23], so I shall merely mention briefly the indirect attack through structural studies. Extensive surveys of this type have been carried out by Loehnberg and Loewenstein, both in the plain or the foreland of the Palestine Mountains as well as in the mountains themselves. Some of the typical problems which they solved by means of electrical resistivity-studies involved: The determination of the course of a concealed water-bearing syncline and its relationship to the catchment-area; the determination of the positions of impermeable layers capable of preventing the infiltration of water into a favorable formation; the attitudes and depths of possibly water-bearing horizons; the fault-pattern and its probable influence on aquifers; the possibility of the occurrence of permeable strata in such a position as to permit contamination of fresh-water horizons by the infiltration of sea-water [24].

Geophysical investigations by these and other geophysicists such as Dr. Walter Stern, have increased the percentage of successful borings for water from about 30 or 40 per cent without geophysical guidance to 85 or 90 per cent where the search has been preceded by geophysical surveys. Incidentally, of course, a considerable amount of information has been obtained on the geological structure of Palestine.

In Spain the Geological Survey of that country has also carried on a geophysical search for water through the mapping by electrical and seismic methods of the extent of certain known aquifers. It is not, however, with reference to water that I wish to cite the example with which I shall close this paper. The final illustration is drawn from a remarkably informative survey carried out in Spain several years ago in connection with the search for coal deposits. The four major methods of geophysics were called into play, namely, electrical, magnetic, seismic, and gravitational. The results thus obtained were synthesized into a structural picture of great commercial and geological importance.

Near the town of Villanueva de las Minas in the Province of Seville, Spain, extensive coal-mining operations are carried on by a private organization. Southeast of the mine the Government owns some property (oblong rectangle marked on Figure 17), which was expected to contain the prolongation of these coal deposits [25]. The coal beds occur near the base of Carboniferous conglomerates, slates, and sandstones, which rest directly upon Cambrian slates. They are covered by Miocene sandstones, shales, and limestones, lying practically horizontal and about 600 feet thick. Prior to the deposition of the Miocene, the Cambrian and Carboniferous formations had been folded into a syncline, its axis striking roughly northwest-southeast. The only surface-expression of this formation consists of an outcrop, near Villanueva de las Minas, of Carboniferous rocks in the northeast limb of the syncline. To the southeast the Miocene conceals the underlying formations, and in the neighborhood of the Guadalquivar River is itself covered in turn by Quaternary alluvium. It is especially these later deposits which have effectively concealed the dislocations which have taken place in this area, and which resulted in the failure of numerous expensive drill-holes to locate the extension of the coal deposits on the government-owned land.

Because of these failures it was decided to apply geophysical methods in an extensive study of the area, in the hope that this might reveal the tectonic pattern and provide the key to the location of the coal beds. The work was carried out in the winter of 1927-28 by the Spanish Geological Survey, directed by Luis de la Pena, and under the immediate supervision of J. G. Sineriz, with the collaboration of the Schlumberger organization.

In the electrical work, resistivity-profiles, equipotential-curves, and depth-determinations were employed. The equipotential-curves served to indicate the direction of stratification of the tilted Cambrian and Carboniferous rocks beneath their masking cover of Miocene and Quaternary sediments. Since the formations occurring in the area exhibit increasing resistivities when passing from Quaternary to Miocene to Carboniferous and to Cambrian, the depth-determinations and the resistivity-profiles were of great value in indicating the locations and thicknesses of these respective formations. The seismic method was useful for the same purpose, since the velocities of transmission of earth-vibrations increase in the same order as the resistivities, and for the same reason, namely, the increasing compaction of older rocks. The greater density of the Cambrian as compared with the overlying rocks permitted the delineation of the syncline by gravitational observations, and the location of several faults which have dislocated it. Magnetic observations were utilized for checking some of the deductions made as to the position of

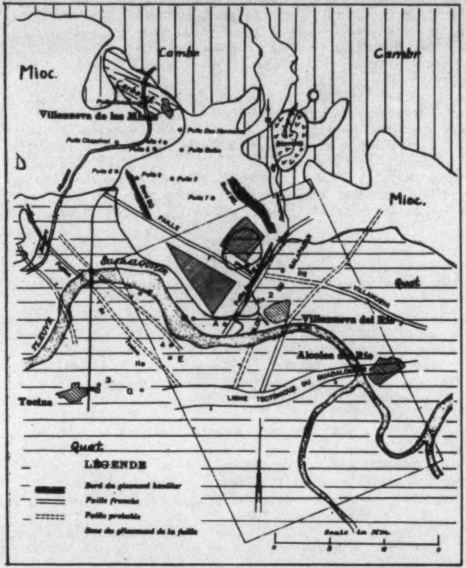

Mioc.
Cambr
Cambr
Carbon
Villanueva de las Minas
D
Mioc.
FAILLE
Guadalquivir
Quat.
Villanueva del Rio
FLEUVE
A
E
G
2
3
4
Alcolea del Rio
LIGNE TECTONIQUE DU GUADALQUIVIR
Tocina
Quat.
LÉGENDE
Bord du gisement houiller
Faille franche
Faille probable
Base du glissement de la faille
Scale in Km.

FIG. 17—MAP OF SURFACE-GEOLOGY, SHOWING ALSO BORDERS OF UNDERLYING CARBONIFEROUS SYNCLINE, INTERPRETATION OF GEOPHYSICAL RESULTS, AND PREDICTED COAL-BEDS

the syncline and the location of certain faults. When the results had been correlated, the fault-pattern stood out clearly and provided the key to what had taken place and why the Government drills had failed to find the coal beds.

The geological deductions made from the geophysical results are shown in Figure 17. It will be observed that the Villanueva Fault cuts off the southern part of the southwestern limb of the coal-bearing syncline. This block between the Tocina and Villanueva faults has been dropped downward to such an extent that the coal horizons are probably too deep to warrant attempts at exploiting them. Another fault, that of the Galapagar, strikes northeast across the syncline. To the east it is succeeded by others, the most important of which is 800 meters away. The block between them, "bloc du Galapagar," is a horst, the northern part of which was uplifted so high that the Carboniferous was eroded prior to the deposition of the Miocene. South of the Villanueva Fault, however, a few feet of strata below the coal beds, at the base of the Carboniferous, still remain. Evidently no coal can be expected here. It is probable that Carboniferous strata continue east of this horst and south of the Villanueva Fault, but faulted downwards in the Guadalquivar zone of subsidence.

From the structural features thus geophysically depicted, it is evident that the northeast border of the syncline, north of the Villanueva Fault and west of the Galapagar Horst, is the only place on the Government property where the extension of the coal beds can be expected to occur within reasonable distance of the surface. Upon this indication a drill-hole was put down, and encountered five exploitable beds of coal of excellent quality. Thus the geophysical survey was amply repaid, aside from the impressive amount of geological data which it produced.

This survey brought together in a striking manner two groups of geophysical techniques whose principal utility has been in widely separated domains of prospecting. Gravitational and seismic methods have attained greatest prominence in the oil-fields, while electrical and magnetic techniques have found their more important application in the search for metalliferous deposits. By thus focusing the four methods on a single problem involving a non-metallic resource, we find a striking proof of the essential unity of geophysical investigation. That unity lies in the common end of any such investigations, namely, the deciphering of the enigmas of the natures and dispositions of hidden geological structures.

In the mining field the tendency has been to concentrate on the smaller details; in petroleum-exploration the geophysicist has had a wider hand and has worked on larger structures; on yet a wider scale have been the studies of those concerned with continental structure. If these different images can, as it were, be produced on the same focal plane, then the cooperation of geophysicists working in their various fields will eventually give us a revealing picture of continental structure. With this as a key, still greater treasurers of mineral resources will in time be unlocked. But in order to achieve this convergence of aims, far closer cooperation is needed than has heretofore existed between the many students of Earth physics in its various branches.

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## PHOTOGRAPHING ROCK-WALLS AND CASINGS OF BOREHOLES

Sherwin F. Kelly

Whether or not a camera should be classed as a geophysical instrument may be open to question. When it is adapted to making stratigraphic studies, however, there is some reason for including it at least as an adjunct to geophysical techniques, such as electrical logging, designed for investigating deep-lying strata. The next best thing to a visual inspection of such deeply hidden beds is to take a photograph of the horizons under investigation. Naturally, such a photograph is not a substitute for a core, but where cores or records have been lost, or in the case of drilling techniques where cores are not taken, pictures of the wall-rocks in place may yield valuable information, and also on occasion serve to augment data obtained by thermal, electrical resistivity, and radioactive measurements.

Such a borehole camera has been designed and used by Dr. Th. Reinhold of the Netherlands Geological Survey. It has been put into practical application by that organization in its search for water-supplies in the Netherlands. Photographic information on the natures of the water-bearing strata was found of considerable help in planning the equipment to be used in the wells.

Figure 1 shows the instrument about to be lowered in a water well, the principal features of its construction, and a photograph of a tuffacious chalk with an open water-vein, taken at a depth of 300 feet.

The apparatus is housed in a brass tube, with a quartz or glass window, g, through which the photograph is taken. Two small electric lamps, f, illuminate the wall of the hole, and the

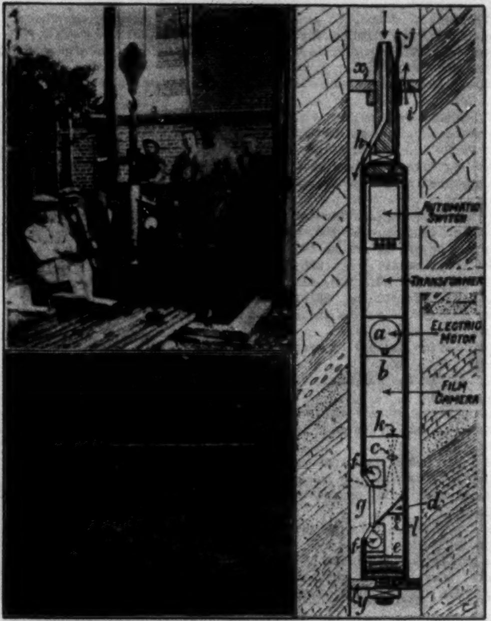

*FIG. 1—(A) BOREHOLE CAMERA READY TO BE LOWERED IN DRILL-HOLE; (B) DIAGRAM OF INSTRUMENT; (C) PHOTOGRAPH OF TUFFACEOUS CHALK IN WATER WELL IN HOLLAND AT DEPTH OF 300 FEET*

mirror, d, reflects the image through the lens, c, on the film, k. An auxiliary lamp, l, lights a compass, e, so that the compass-bearing of the photograph is recorded on its margin. A small moving picture camera, b, can be used, with an electric motor arrangement, a, for changing the film after each exposure. Current can be supplied from the surface by a cable, j, through the drill-stem, or batteries may be carried in the instrument itself, and the switching controlled by only one wire running to the surface.

The instrument is closed off at each end by washers, x and y, of felt and rubber, with circular brushes arranged so as to clean the walls as the instrument is lowered through the drill-hole. The mud-laden fluid is washed out of the section being photographed by forcing clean water, or in the case of oil-strata, benzine or gasoline, through the drill-stem and the pipe, h. The dirty water passes out of the opening, i, in the upper washer. By providing washers of various sizes, a single camera can be adapted to any size drill-hole from one of four inches in diameter up to holes of 12 inches in diameter or more.

In operation the apparatus is attached to the drill-stems

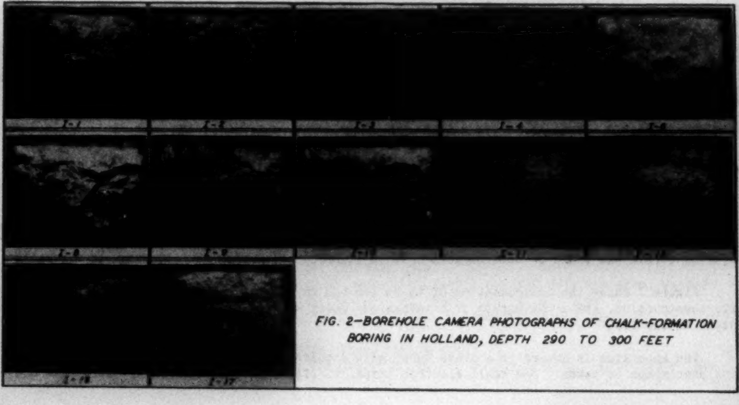

*FIG. 2—BOREHOLE CAMERA PHOTOGRAPHS OF CHALK-FORMATION BORING IN HOLLAND, DEPTH 290 TO 300 FEET*

and lowered to the proper depth. After washing the section of the hole, the light is turned on and the exposure made. By rotating the camera, a series of photographs may be taken, giving a complete picture of the circumference of the hole. Thus the angle at which the strata cut the drill-hole may be accurately measured, and the direction of dip indicated. Any desired number of sections of the borehole may be photographed by raising or lowering the instrument, and the number of pictures which may be taken in a single run is, of course, limited only by the length of the film in the camera. A photoelectric cell may be included in the apparatus so that the exposure would be permitted only when the walls and window had been washed clean enough to get a good picture.

An evident application of this technique is to old holes where records or samples have been lost. The condition and nature of the rocks traversed may be photographed and key-strata identified. Even during the progress of drilling, photographs of the uncased portions of boreholes will facilitate the recognition of the general fissured or cavernous nature of the rocks, and the identification of strata of shale, coal, sandstone, limestone, etc.

In oil-work the photographs will show whether or not a producing stratum was a homogeneously saturated sand, or whether the oil was draining through fissures, or whether it came from a porous and fractured limestone. The effects of shooting the well can be recorded photographically.

Another field of application of less interest to the stratigrapher than to the well-driller is the possibility of inspecting casings. Damage due to corrosion, cutting, wear, etc., can be readily located photographically, and remedial measures thus facilitated. Imperfectly seated casings can be inspected, and bulging or unscrewed tubes found. The actual results of reaming will be made visible, and a photographic inspection before plugging back crooked holes could be of considerable assistance in this process. In wildcat drilling showings of oil contaminated with water may be investigated to determine whether the water occurs in the sand or is coming from a leaky or imperfectly cemented casing.

As far as the geophysicists are concerned, the principal utility of such an apparatus is to check stratigraphic data obtained by other techniques such as electrical logging, and to fill in the gaps resulting from lost records of old holes. Dr. Reinhold's borehole camera should therefore be of considerable assistance not only to the oil-exploration engineer, but also to the geophysicist who is interested in the stratigraphy and structure of continental areas.

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## THE APPLICATION OF TELLURIC CURRENTS TO SURFACE PROSPECTING

Marcel Schlumberger

The electrical methods for surface-prospecting have been well developed in the last 20 years. The method involves, in the classic form, the sending of an electrical current into the soil, by means of two electrodes A and B, and studying the potential distribution at the surface, by measuring the difference of potential between pairs of points such as M and N. The points M and N are usually placed on a line between, and equidistant from, A and B. By increasing the distance AB, the current sent into the Earth, and likewise the distribution of surface-potentials, become influenced by regions of greater and greater depth below the surface. By varying the form and dimensions of the electrode-arrangements AMNB, called a "quadripole," one may make valuable deductions concerning the nature or thickness of beds, if one knows the electrical properties of these beds. On the other hand, if the form and dimensions of the electrodes AMNB remain fixed, the depth of penetration of currents in the Earth remains, so to speak, almost constant, although it tends to increase where the subsoil is more conductive, and conversely. Therefore, if one moves the constant-dimension quadripole over all the terrain to be investigated, one achieves approximately a horizontal exploration. This permits a study of tilted beds or faulted horizontal beds.

When the particular problem becomes deep, of the order of 2000 meters, or more, it is necessary to increase the distance between the current-sources AB to a length such that the work becomes very troublesome, especially if the region is wooded. At the same time, the separation of the points M and N must be likewise great (for example, one km) in order to obtain differences of potential which are not too small; the measurement of potential differences across MN is then difficult because of the presence of parasitic potentials, due to a flow of telluric currents in the Earth, and the order of greatness of these currents may exceed the quantities to be measured.

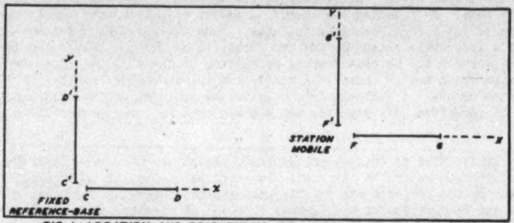


FIG. 1—LOCATION AND ORIENTATION OF LINES OF MEASUREMENT

It would be desirable, in order to avoid the inherent difficulties of the electrical method with large spacings, to replace the foregoing by a new method in which one does not send an artificial current into the Earth, and in which the measurements concern only the natural field due to the telluric currents.

Numerous studies made on the telluric currents over a long period of time, and over the surface of the globe, show that they are subject to a variation of long period (daily variation), and also to oscillations of small period and of great amplitude which one observes in connection with magnetic storms.

The intimate relation between these two latter phenomena and their common solar origin has been established by Mr. Basler in 1912. Observations were made on lines of many tens or hundreds of kilometers in length, the direction of the telluric field at any given instant being deduced from its components on two rectangular lines of measurement.

A number of studies have also been made on the flow of telluric currents at the surface of the Earth and have demonstrated the existence of a certain number of systems of telluric eddies, progressing around the poles of the Earth and making a complete revolution in 24 hours. This confirms the solar origin of telluric currents. These systems become deformed, more or less, according to continents and oceans, in order to take the path of least resistance.

The present study concerns primarily the telluric variations of regional character observed at all times at the surface of the Earth, especially outside the periods of magnetic storms. The periods may vary from a few seconds to a few minutes, the most common type having a period of 20 seconds. In addition to the above, the study is designed to show the possibility of using, practically, the telluric currents in the prospection of the subsurface, rather than to provide a contribution to the scientific study of the phenomena and their origin, such as solar magnetic field, friction of the wind, or capillary electric phenomena caused by the rain or the sea. (It is possible to light an electric bulb by the currents generated by the filtration of sea-water into the sands of the shore.)

Our first serious studies were made in Normandie, near Lisieux. It was first necessary to study the regional nature of the telluric variations. At a location called a "fixed base," two lines CD and C'D', of equal length (500 meters), were arranged at right-angles, the points C and C' being near to one another. At another location called the "mobile station," two lines FG and F'G' were arranged, also perpendicular to one another and of 500 meters length, and parallel respectively to CD and C'D', with F near to F'. An apparatus for measuring potential difference was connected in series with each line. It is obvious that measurements on two parallel lines, at the same instant (the time may be impressed on the film in any desired manner), present a comparative reading, but that comparison of readings obtained on two perpendicular lines, one at the fixed base and one at the mobile station, is difficult to make. In other words, the projection of variations of the field in a single direction is well preserved in the whole region studied.

We have studied whether it was possible to calculate the measurement obtained on the line FG, for example, from the measurements obtained on the two lines CD and C'D' at the other station. On Figure 1, we designate by x, y, and X the coordinates of curves registered, respectively, on CD, C'D', and FG, these coordinates being plotted with respect to an arbitrary origin (for the short lines, the influence of the dissymmetry of electrodes is no longer negligible, as in long lines, in comparison to the potential due to the telluric field alone). The true origin corresponds, for each line, to a zero-projection of the telluric field on that line. One finds a simple experimental relation between the small simultaneous variations dx, dy, dX of these coordinates

$$dX = \lambda\, dx + \mu\, dy$$

If one considers the lines CD, C'D', and F'G', and designates by Y the coordinates on F'G', one has

$$dY = \lambda'\, dy + \mu'\, dx$$

$\lambda$, $\lambda'$, $\mu$, $\mu'$ are constants.

These two relations have been verified experimentally during many intervals of time, sufficiently small so that the potential variations of extra-telluric order are negligible, by measuring the variations along the coordinates in each of the time-intervals, and by verifying that the above coefficients were constant.

Combining both equations, they indicate that the azimuth (dY/dX) of an elementary field-variation at the mobile station is a function of the azimuth (dy/dx) of the corresponding field-variation at the fixed station, the two directions being called "complementary." In other words, for any pair of complementary directions, the relation $(dX^2 + dY^2)/(dx^2 + dy^2)$ of the variations of the particular field is a constant.

For a distance not too great between the base and the mobile station, and for a homogeneous subsoil or sufficiently uniform structure, the complementary directions remain practically parallel. $\lambda$ and $\lambda'$ represent practically, in this case, the component of the field in the directions CD and C'D', respectively. $\mu$ and $\mu'$ are the coefficients, generally small, which are a function of the distortion, between the fixed base and the mobile station, of the components of the field along C'D' and CD at the fixed base.

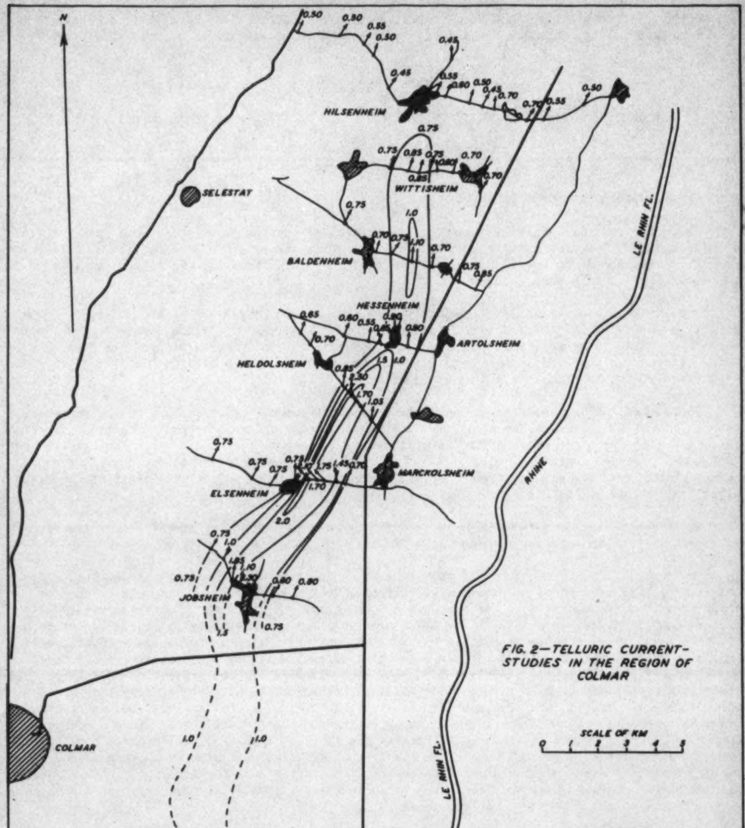
Further work was done in 1934, 1936, and 1937 on the salt-domes of Alsace, at Rustenhart, Hettenschlag, and in the region northeast of Colmar.

The geological conditions of the problem were as follows: The plain of Alsace, resulting from the partial erosion of an old massive mountain, in the Vosges on the French side and the Black Forest on the German side, is composed of conductive Oligocene marls covering highly resistive salt. At certain points, these salt-formations are upthrust into the marls in the form of salt-domes. The plain is bounded on the east and west by chains of crystalline mountains of very high resistivity. The telluric currents which circulate in the plain of Alsace are found to be, in a general way, confined in a channel. At a given point, the variations of the telluric field maintain, for a time, a direction about constant, which we call the "preferential direction." This is deduced from the fact that the variations observed, at any station, on two rectangular lines are about alike except for an amplification-coefficient. The telluric currents circulate in the same way as water in a stream: The current-lines of the water have about a constant direction at a given time at each point, but vary from one point to another as the stream encounters meanders or obstacles in the bed. It is the same for telluric currents when they encounter domes of resistant salt; the telluric field increases at the surface, just as the water rises when encountering a submerged dam.

We present, in Figure 2, the charts showing the results of our work in the plain of Alsace during 1936 and 1937. The arrows indicate the "preferential directions" at each point and the figures the ratio of telluric fields at each station with respect to the telluric field observed simultaneously at a fixed reference-station; hence the reference-point has been arbitrarily chosen.

The salt-domes about Hettenschlag (south of Colmar) and to the west of Marckolsheim are neatly defined. In particular, the results in the region of Hettenschlag coincide remarkably with the results of electrical studies, and with gravimetric work (torsion-balance and static gravity-meter) which had been done previously in the region.

In 1937 and 1938 we tried the method of prospecting by telluric currents in the southern part of Sumatra, with the authorization and assistance of the Bataafsche Petroleum Maatschappij. The first month, we used lines which were too short, resulting in measurements of very low intensity, due probably to the insular nature of Sumatra, the ocean being a path of very low resistivity compared to the land. With lines of 1000 meters, in place of 80-meter lines which were sufficient in Alsace, we obtained, on the other hand, remarkable results.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HILSENHEIM
WITTISHEIM
SELESTAT
BALDENHEIM
HESSENHEIM
ARTOLSHEIM
HELDOLSHEIM
MARCKOLSHEIM
ELSENHEIM
JOBSHEIM
COLMAR
ST CROIX EN PLAINE
HETTENSCHLAG
NEUF-BRISACH
LE RHIN FL.
RHINE
LE RHIN FL.
SCALE OF KM
0 1 2 3 4 5
LEGEND
2 EQUAL-RESISTIVITY CONTOUR
VECTOR INDICATING THE MEAN DIRECTION OF CURRENT
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0.50
0.55
0.50
0.45
0.45
0.55
0.60
0.50
0.45
0.70
0.70
0.55
0.50
0.75
0.73
0.85
0.75
0.80
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0.85
0.75
1.0
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1.10
0.70
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0.80
0.70
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1.0
0.85
2.30
1.70
1.05
0.75
0.75
0.75
0.73
1.75
1.45
0.70
1.70
2.0
0.75
1.0
1.85
1.0
2.30
0.73
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1.0

FIG. 2—TELLURIC CURRENT-STUDIES IN THE REGION OF COLMAR

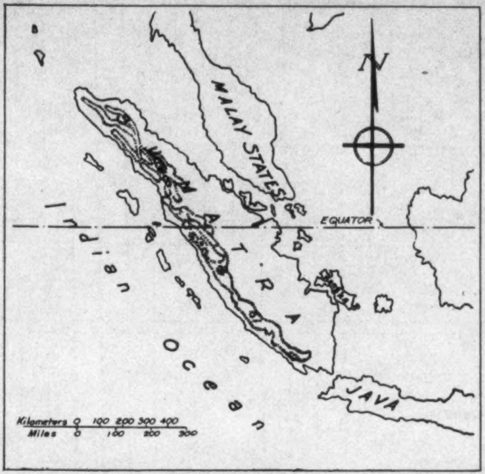
N
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FIG. 3—MAP OF SUMATRA

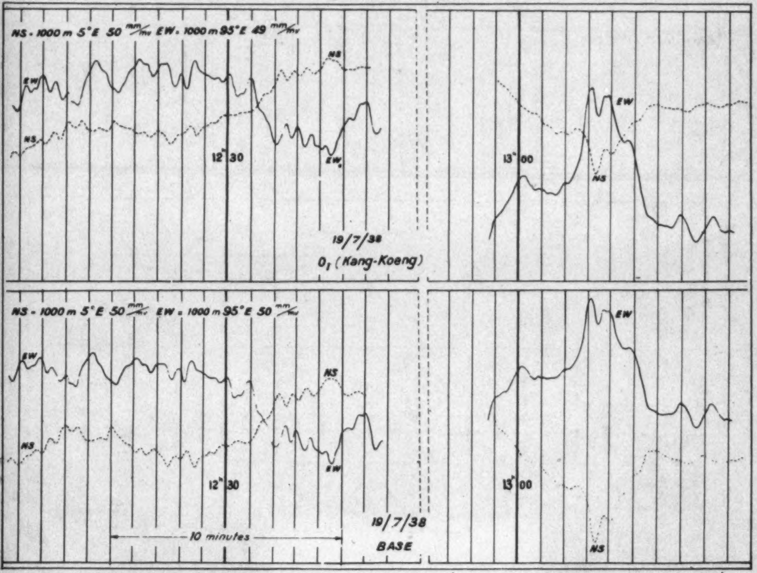

FIG. 4—EXAMPLE OF MEASUREMENTS OVER A LONG DISTANCE (KANG-KOENG AT 50 KM FROM THE BASE) CORRELATION OF CURVES IS EXCELLENT

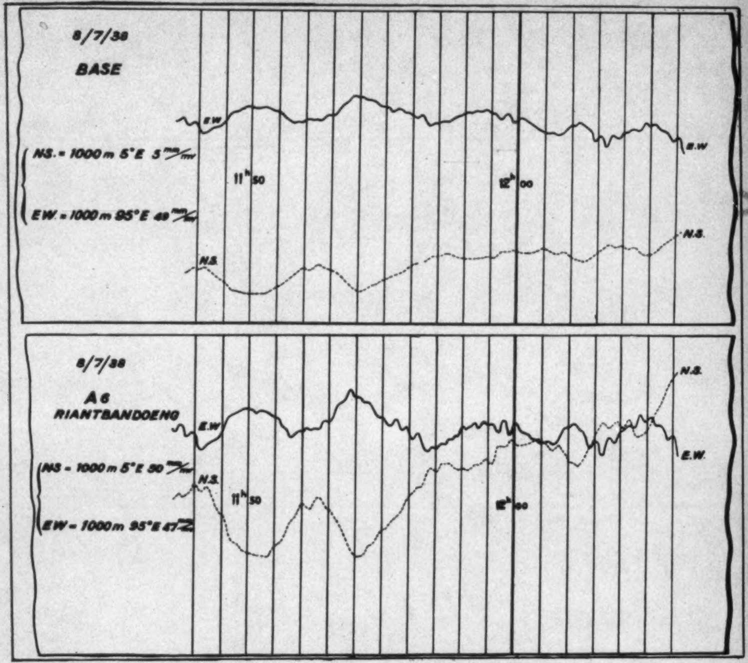

FIG. 5—EXAMPLE OF A LARGE INCREASE IN VARIATIONS, NS=2.1

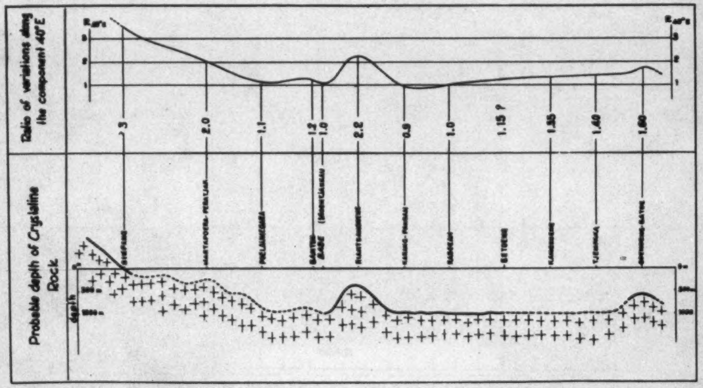

FIG. 6—DETERMINATION OF DEPTH OF CRYSTALLINE ROCK

The variations of the telluric field are generally more pronounced in a zone running parallel to the volcanic range, but the very definite channel of current is not present in Sumatra as it was in Alsace.

We proposed to study the depth of the crystalline substratum of practically infinite resistivity which occurs under the sedimentary beds, and outcrops at the southwest range along the Indian Ocean and at the island of Bangka (Fig. 3). We worked a profile oriented approximately perpendicular to the tectonic axis.

At each mobile station we made measurements along lines in four directions, and studied separately the decrease or increase of components of the field, along these directions, between the mobile station and the fixed reference-base at Moentjakkaban. The correlation of curves obtained along parallel lines remained good for distances exceeding 70 km between the station and the base. We show, in Figure 4, an example of good correlation of measurement over a great distance.

From the group of results, it appears that the variations of the telluric field observed at stations in an alignment parallel to the tectonic axis do not suffer distortion, and that their decrease or increase is insignificant (a longitudinal barrier in a stream does not cause an appreciable disturbance of current, either in direction or in speed of flow). On the other hand, when the stations are arranged along a line perpendicular to the direction of stratification, the variations are quite strongly increased (Fig. 5) above the regions where the crystalline rock rises; their distortion is negligible. We show, in Figure 6, the results for the component north 40° east, which is approximately perpendicular to the tectonic axis. These results coincide very well with the depth of the crystalline rock calculated in this area by other geophysical methods (gravimetric and seismic) and from a few well-depths.

Finally, for the variations of telluric field oblique to the tectonic axis, one observes great distortion reaching deviations of many tens of degrees. The current tends to pass around isolated resistant obstacles, or pass over continuous resistant barriers. The increase or decrease observed is intermediate between that obtained, respectively, for the components parallel and perpendicular to the tectonic axis.

## Conclusions

We believe that the foregoing results permit us to be very optimistic concerning the future of the method of prospecting the subsurface by the study of telluric currents. Without doubt, the method is very new to visualize, at present, the application to complex cases, such as the study of a horizon covered by three zones. The electrical method is much better adapted to such studies. On the other hand, in a simple case of a substratum covered by a single zone, for example, the telluric method presents the advantage, over the resistivity-method, of avoiding the long lines for sending current when the problem is deep. It also allows the possibility of working more rapidly and economically over large areas.

The telluric method thus seems to be an excellent method for prospecting large areas of subsurface or for problems at great depth (the petroleum-research actually tends always to greater and greater depth). The gravity-meter is likewise applicable to the same sort of problem and one or the other may be used, depending on whether the electrical properties or the density of the formations offer the larger differentiation.

Acknowledgments--Particular credit is due to H. G. Doll who designed much of the apparatus and perfected the technique, and to Mr. Favre who made most of the measurements and interpretations. We wish to thank them for their valuable contributions. We wish also to thank the Bataafsche Petroleum Maatschappij whose cooperation made possible the Sumatra work used to illustrate this paper.

Vice-President, Compagnie Generale de Geophysique,
Paris, France

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## MEASUREMENTS OF RADIOACTIVITY FOR STRATIGRAPHIC STUDIES

H. Landsberg and M. R. Klepper

Biological as well as geological research has made very successful use of the qualities that the physicists have detected in radioactive substances. Outstanding examples for the vast new

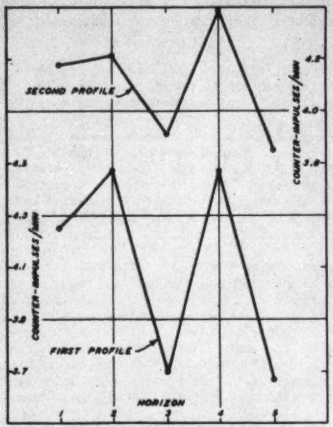

FIG. 1—RADIOACTIVITY OF TWO PROFILES OF SILURIAN STRATA IN CENTRAL PENNSYLVANIA

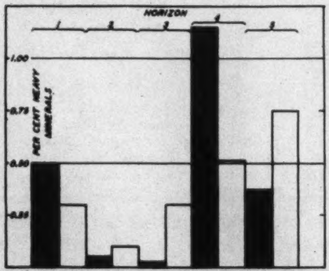

FIG. 2—PERCENTAGE OF HEAVY MINERALS IN LAYERS OF TWO PROFILES OF SILURIAN STRATA IN CENTRAL PENNSYLVANIA

fields opened in this part of the border-land between the disciplines of geology and physics are the "radiothermal geology" [July, 1909, see 1 of "References" at end of paper] and all that is connected with the use of the radioactive disintegration clock for the age-determination of rocks and minerals [2].

In structural geology, not unlike to recent biological uses of radioactive material, their "tracer" properties were helpful. Changes in Radon concentration in soil-air, especially accumulations, led to hidden crevices and fault-zones. High contents of Radon in spring-water gave clues as to the types of rocks they had flowed through [3, 4]. One specific application of the small admixtures of radioactive material, however, has only lately found some attention and that is their use in linking beds of sedimentary strata otherwise only poorly identified because of the lack of fossils or other characteristic properties. To be useful for this purpose, two conditions have to be fulfilled: (1) The amount of radioactive material per unit-weight of rock in a given horizon should be uniform over a large area; (2) this same amount should change fairly rapidly in the vertical succession of layers.

To test the first premise of a method of radioactive stratigraphy, a short digression into the processes of deposition of radioactive material in the sedimentary rocks seems indicated. The sedimentary rocks derive their radioactive admixtures from the radioactive contents of igneous rocks and radioactive substances dissolved in the sea-water. The method of deposition can be threefold, namely, gravitational sedimentation of minerals with radioactive constituents, chemical precipitation, and biochemical accumulation. The first case is the simplest. In a given sedimentation-area detrital material from igneous rocks will tend to be uniformly mixed and deposited over a considerable area of the sedimentation-basin. There is no reason to assume that the radioactive constituents in the newly formed sediment would have a spotty distribution. In the case of chemical or biochemical action the conditions of oxidation and reduction, or the type and distribution of animal or plant-life would enter as possible selective processes that might produce heterogeneous distribution of the radioactive precipitates. Very little is known on this latter type of deposition. It is remarkable that in spite of very low concentration of radioactivity in sea and lake-water, bottom-sediments often contain very high concentrations of radioactive material [5, 6, 7]. While Piggot [8] interpreted his data from deep-sea deposits as indicating a purely chemical process, Evans and collaborators deducted from their measurements on the radioactivity of planktonic marine life that the biochemical processes are also of importance. (Especially interesting in this connection are the high values of radioactive material in globigerina oozes and it seems that this question could be solved experimentally by placing these animals in aquaria containing some highly radioactive substances and comparing later on the activity of the shells with those of controls kept in ordinary water.) In the recent lake-deposits investigations by Kurbatov, chemical action is also involved in the accumulation of radioactive material. It remains to be shown by investigation of a large number of samples from one sedimentation-area how uniform the content of radioactive substances is, although there can already be no doubt from the findings of Kurbatov that in different sedimentation-areas the quantity varies considerably. This is favorable for any attenpt at correlation inasmuch as otherwise similar and contemporary deposits are kept apart.

This leads to the question of the second prerequisite of a radioactive correlation-method, the change in radioactive constituents from horizon to horizon. This particular postulate seems to be well fulfilled in many cases. One of the earliest examples was given by Ambronn, who measured in an oil-well. There the differences were thought to be due to accumulations of radioactive material in the oil-horizons due to the fact that oil is a good solvent for Radon. Since then several surveys in oil-wells have been made. Instead of lowering instruments into the well, tests can also be performed on core-samples [10]. Such tests revealed that within relatively short vertical distances very noticeable differences of concentrations of radioactive matter can be found in the rock itself, independent of the Radon carried by the oil.

Actual use of the radioactive parameter for stratigraphic correlation has only been made within the last two years. Spak [11] has published measurements from three boreholes in which a radioactive sounding was made. Several horizons within a thickness of strata of 60 meters could be identified in the three holes by means of their activity. There are several minor fluctuations in activity in each of Spak's curves which find no corresponding activity in the others. This is probably due to the difficulty of measuring in a well, where gaseous emanations can freely circulate from one level to the other and with their disintegration products obscure the primary activity of the horizons. For this reason a series of experiments in the laboratory were conducted by the authors on rock-samples from corresponding horizons in two profiles five miles apart. They originated from five Silurian horizons in central Pennsylvania, well identified by other geological evidence. The main aim was to test the hypothesis that the activity-changes in vertical directions in the profiles are the same. The result of these tests is shown in Figure 1. The maxima and minima of activity in the two profiles correspond well. The absolute values in the second profile, however, are somewhat lower. This is most likely due to weathering of the rock-samples which were taken from old outcrops, in the second profile, whereas the samples of the first profile originated from a recent road-cut. Horizons 3 and 5, both shales, seemed to be nearly barren of radioactive material, whereas the sandstone and quartzite horizons 1, 2, and 4 showed some activity. Since Clark and Botset [12] in testing the geological significance of radioactive measurements made at the surface had found a close correlation between Radon and the percentage of heavy minerals in the soil, the heavy mineral-content in our samples was determined. The heavy mineral-percentages, as shown in Figure 2, do not indicate a correlation between corresponding horizons and do not show the characteristic difference between the sandstones and shales that the radioactive profiles revealed. If, however, the types of heavy minerals are inspected, interesting relations become obvious. Table 1 shows the heavy minerals found in the five horizons.

Table 1--Types of heavy minerals in various horizons

| Horizon | Formation | Heavy minerals | Radioactivity |
|---|---|---|---|
| 1 | Tuscarora quartzite | Zircon (a), tourmaline (f), rutile, chlorite, (xenotime) | + |
| 2 | Castanea sandstone | Zircon (a), tourmaline (f), rutile, (xenotime) | + |
| 3 | Rose Hill shale | Pyrite (a), fluorite, chlorite, garnet | - |
| 4 | Keefer sandstone | Zircon (a), tourmaline (a), rutile, hematite, chlorite, muscovite, (monazite) | + |
| 5 | Bloomsburg shale | Hematite, chlorite, apatite, biotite, muscovite, barite, fluorite, rutile | - |

a = abundant; f = frequent; + = positive; - = negative.

All active horizons show tourmaline and especially zircon in abundance, minerals which are absent in the inactive horizons. They also have traces of such minerals as monazite and xenotime not found in the inactive samples. Because of the close chemical relationship between zirconium and uranium and thorium, there is good reason to assume that the activity in these horizons is due to enclosures and isomorphous presence of radioactive material in zircon and related heavy minerals, a fact that Clark and Botset had also suspected from their soil-surveys. The advantage of a test for radioactivity, however, is that it consumes much less time than a complete petrographic analysis of heavy minerals.

The experimental procedure for determining radioactivity in the field and laboratory has changed in the last few years from electrometric tests to application of Geiger-Müller counters. The former is mainly an alpha-ray method, the latter a gamma-ray procedure. In our work both methods were employed [13]. The Geiger-Müller counter has been used for experiments in the laboratory by Rothé and collaborators for the determination of radioactive material in igneous rocks [14], also by Evans; and by the Russian workers [Spak, Gorshkov, and Kurbatov, 15] in boreholes.

The growing literature on radioactive stratigraphy shows that the somewhat neglected radioactive methods are finding their place in geophysical work applied to structural geology.

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## GOVERNMENTAL ACTIVITIES IN GEOPHYSICS RELATING TO PROSPECTING

### PART I--HISTORY AND ACTIVITIES OF THE SECTION OF GEOPHYSICS OF THE UNITED STATES GEOLOGICAL SURVEY

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(Published with the approval of the Director, U. S. Geological Survey)

Historical--From the beginning of time, all ingenuity of mankind has been concentrated upon the methods of finding gold and unusual deposits in the earth. An illustration (Fig. 1) from the old treatise by Agricola, "De Re Metallica," published in 1580, will serve to show the implicit faith of that generation in divining methods. However, it was not until 1920 that real progress was made in prospecting by using the latest advances of the physical sciences. The public interest was stimulated by the successes of these methods on the part of commercial operators, and governmental agencies received many requests for information concerning their reliability. There were also, in the late 1920's, high-pressure mine-promotion schemes which used geophysical methods in a very questionable manner, symbolized in Figure 2 as of 1928 by an electrified forked stick. Authoritative information concerning such practices for public protection was needed to curb such notorious undertakings. Dr. Scott Turner, then Director of the United States Bureau of Mines, thoroughly understood the situation and was first in the governmental departments to recognize the possible value of a study of modern prospecting methods. The Bureau of Mines began this investigation by employing Drs. A. S. Eve and D. A. Keys of McGill University for short periods in the summer in 1927. Their first publication [see 1 of "References" at end of paper] served to illustrate the fundamental scientific principles which underlie geophysical prospecting. This was followed by a second publication [2] giving the results of field-tests. In the light of the rapid improvements during the intervening ten years, these two papers take a historical position.

Later a full-time position under Civil Service was planned by the Bureau of Mines for continuous investigations and research concerning geophysics and its applications to prospecting. It was Turner's idea that, since the oil-industry had been making very rapid progress with good results, if mineral mining could also benefit to the same degree, it would be of great help to that industry.

Public information service--There was at that time only a very limited amount of public information available upon which to build, and progress was very slow. What information was available was published in foreign languages not easily accessible to the public. It was, therefore, at once decided to make a review of such scientific literature and also, if possible, to permit the mineral industry to benefit from this review. The Bureau of Mines, therefore, initiated an abstract-service which endeavored to mention publications of importance from all languages, as well as to review patents. It aimed not only to serve the Section of Geophysics of the Bureau but also all operators and scientists who were interested in geophysical prospecting. Since it served this much-desired need, this publication was well received in the United States and in other countries. It was first issued monthly as an information circular by the Bureau of Mines and is now issued as a quarterly by the United States Geological Survey. So far over 5000 abstracts have been published.

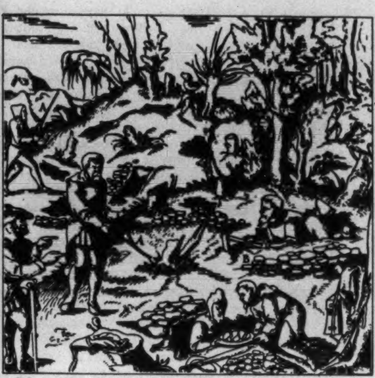


*FIG. 1—THE DIVINING ROD, AGRICOLA DE RE METALLICA, 1580*

Establishment of a geophysical staff--As soon as it was realized by the oil-industry that geophysics was applicable in locating oil-deposits, attention was focused by the industry upon this branch of science. Precise physical measurements, mathematical analysis, and geologic theory were directly applied. Because of the inherent difficulty of the problems whose solutions required a special technique of measurement as well as of mathematical analysis, the instrumental costs and the expenses of field-surveys were high, and only well-financed companies could afford to experiment with the methods.

Under these conditions a staff was gradually assembled by the Bureau of Mines from Civil-Service candidates with the proper specialized training. A carefully balanced staff was most essential for the analysis of the many geophysical questions which arose--as well as for investigations being undertaken at the present time. Since the geological effects studied are usually reflections of details in the rock-masses, careful geologic interpretation of the observed geophysical effects is essential. The mathematical theory for proper analysis of field-observations has received much consideration. While the foundation of this work is the theory of fields whose mathematical possibilities have been clearly defined, and therefore offer little to the extension of the mathematical sciences, mathematical studies are nevertheless complicated because of the great number of discontinuities inherent in geologic formations. To this must be added a large number of other physical factors of an uncertain nature that exist in the Earth and are not readily incorporated in a mathematical equation. The work is further complicated because a large amount of field-research is necessary for each geologic situation, which differs of course in each area or district. The proper type or kind of physical measurements which will prove most effective can only be gained by actual experience.

Transfer of Section of Geophysics to the United States Geological Survey--In 1936, the Section of Geophysics was transferred from the United States Bureau of Mines to the United States Geological Survey. At the present time, because of financial limitations, pilot-research activities alone are possible.

Magnetic work--Before the organization of the Section, the Bureau of Mines through Heiland [3] made a search of hidden deposits of titaniferous magnetite at Caribou, Colorado. Both the vertical and horizontal magnetometers were used, and a start was made in measuring both the absolute and relative values. Later other magnetite-deposits in Michigan, New York, and Pennsyl-

*FIG. 2—"MILLIONS OF DOLLARS HAVE BEEN SPENT IN PROBING THE EARTH BY CREDULOUS PEOPLE ON EVIDENCE OF THE FORKED STICK" (FROM "THE EXPLOSIVE ENGINEER")*

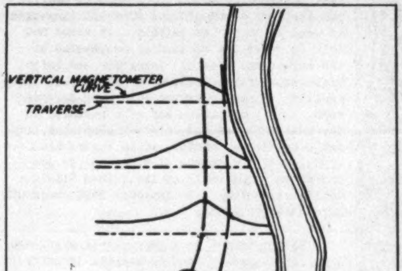


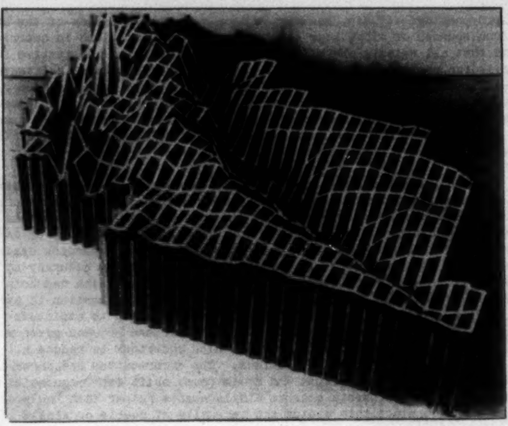
*FIG. 3—VERTICAL-MAGNETOMETER OBSERVATIONS ON A HEMATITE ORE-BODY SHOWING CROSS-FAULT*

vania were studied by E. F. Stratton and J. W. Joyce [4] using vertical and horizontal magnetometers. At that time there was a gradual transition from the older dip-needle methods to the more precise magnetic methods of observation using the magnetic variometer. It was found at Mineville, New York, that, even with such precise measuring instruments, the syenite, granite, and gabbro, although magnetically much weaker than the magnetite, were nevertheless of such large volume compared to the included magnetite ore-body that the differentiation between ore-body and country-rock was difficult, especially since the ore-body was podlike in form and unfavorably disposed. Later more work was done on deposites of hematite in beds of slate and other similarly metamorphosed rocks. It was found that the hematite-body was non-magnetic in massive volumes and as such was not discernible. However, the deposits of hematite were often flanked by magnetite, which permitted a clear definition of the boundary of the ore-body. Figure 3 shows a portion of the vertical magnetic anomaly and the ability to find the continuity of the ore-body in cross-faulted horizons under glacial drift. It was also possible in this area to identify steeply dipping beds, each having only a slightly different magnetic susceptibility, under glaciated overburden.

Experiments were made by Lee [5] upon the nickel ore-deposits in the Sudbury District, Ontario. The ore-bodies were veins of pyrrhotite, pentlandite, and chalcopyrite. The results obtained in this area were subjected to a very careful mathematical scrutiny, and it was found that such observations could be rationally analyzed. Work in this area also showed the advantage of using several geophysical methods [6] on geologic bodies in order to differentiate between them when there are no outcrops visible. In this area there were also a great number of basaltic dikes which were magnetic to the same degree as the ore-bodies. However, it was possible to differentiate between the ore-bodies and the basaltic dikes by combining electrical inductive methods with the magnetic surveys. It was more economical first to discover the magnetic anomalies with a magnetometer and then ascertain the character of the anomaly by the electrical method. This work was done by cooperation between the United States Bureau of Mines and the Canadian Geological Survey in two consecutive summers. The friendly relations established between the Canadian Geological Survey and the United States Bureau of Mines was of mutual benefit to both countries.

Later the American Askania Corporation made a very decided improvement in the magnetic variometer by introducing a needle which was designed to compensate for temperature-changes. This step permitted contouring the change of elevation of the granitic basement in the Amarillo area of the Texas Panhandle. It was possible in this area to measure variations of magnetism of the order of two gammas and also to correlate such small changes with the topography of the granite ridge. The topography of the basement agreed with the areal geology as determined by N. W. Bass of the United States Geological Survey and was also confirmed by drilling. A comprehensive manual upon the use of the magnetometer for making such surveys was written by Joyce [7].

Recently further magnetic studies were made by E. L. Stephenson upon laccoliths in the Highwood Mountain area of Montana with a view to determining, if possible, the feeders of the laccoliths. Figure 4 shows the magnetic anomaly of a portion of a laccolith and the advantage of magnetic models for interpreting the geology.



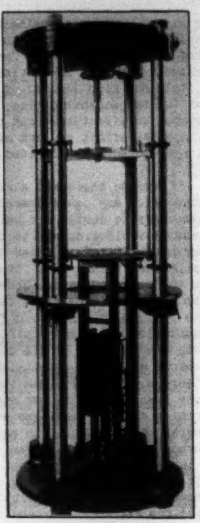


FIG. 4—PICTURE OF MODEL OF MAGNETIC ANOMALY OVER A LACCOLITH

FIG. 5—MASTER MECHANICAL OSCILLATOR FOR MEASURING VERTICAL MOTION

Other magnetic surveys were made on deposits of chromite. A talc schist body containing lenses of chromite and magnetite near Casper, Wyoming, is under detailed examination at the present time. The magnetic survey is coordinated with geologic mapping and mineralogic and chemical investigations of the magnetic minerals. A brief magnetic investigation of a chromite-zone in basic rocks in southwest Oregon was also made.

A preliminary survey has been undertaken in the lower Florida Peninsula to determine if possible the topography of the crystalline basement. Fifteen east and west magnetic traverses have been run with readings taken every mile. The United States Coast and Geodetic Survey has cooperated by ascertaining the absolute magnetic intensities at two stations, one at Ft. Myers, the other at Gainesville.

It was found in making this survey that it was of considerable advantage to use null methods in the field upon the magnetic variometer of the Schmidt type by auxiliary coils permanently mounted upon the tripod of the magnetometer. This avoided latitude-adjustments which affected the temperature-compensation of the needles. It was also found of advantage in the horizontal-component magnetometer, since it avoided by its use the correction for the vertical component of the magnetic field.

Magnetic studies with refinements of measurement are still of major importance in geophysical surveys, especially when coupled with better methods of interpretation as discussed by Roman in Part III of this paper.

Seismic investigations--The Section's activities upon seismic studies have not attempted to discover salt-domes, anticlines, igneous plugs, and structural features intimately associated with oil; neither has it entered the

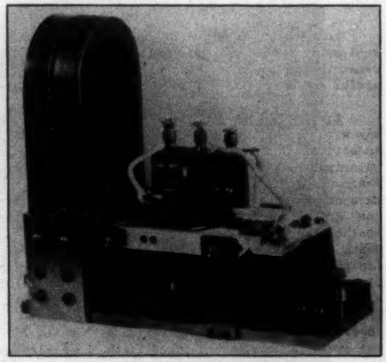


FIG. 6—VERTICAL SEISMOMETER

field of reflection seismic prospecting. It has, however, made a very careful study of the absolute motion of the Earth from sources of vibrations caused by blasting operations in quarries and mines. It has been found that all seismic-vibration information is largely qualitative in character and is used primarily for measurements of time of arrival of diffracted elastic waves. Little has been learned of actual ground-motion because the observations have been obscured by all of the eccentricities of the recording, filtering, and amplifying apparatus which produce a composite effect that can not be separated into its constituent components; nevertheless, such a composite effect or lack of purity of recording is sufficiently selective to permit recognition of reflected and refracted waves in seismic prospecting.

Because there was also a certain legal angle which stipulated exactly the limits of vibration which may cause damage, extra refinements of measurement were required. It was therefore necessary to design and build precision calibration-equipment which could simulate vibrations caused by blasting and to test the accuracy of the recording instruments and the errors of measurement. Figure 5 shows the master mechanical oscillator for testing seismic recorders described by Lee and Irland [8]. It was found that there were no instruments which had the accuracy as well as the range of motion necessary for this work, so a seismometer was developed which had both for the vertical component of motion, as shown in Figure 6. For its principle of operation it used the phase-modulation (see Fig. 7) of high-frequency currents which were changed to amplitude-modulation and then rectified to the low frequency or ground-motion. Irland [9] has given a complete analysis of the design of such a precision-seismometer which undertook to reduce all sources of error, especially transient vibrations, to a minimum. The error-curves are shown in Figure 8. They are less than one per cent in amplitude and 8° in phase-shift for frequencies of more than six cycles per second. These instruments measure displacements rather than the acceleration or the velocities of the ground since this avoids the necessity of double or single integrations inherent with measurements of acceleration and velocity. The same percentage of accuracy was attainable over an amplitude-range of 20 microns to two millimeters. Disturbances at a large number of different quarries were measured and it was found that the absolute motion of the ground was exceedingly complex, something like the movement of a mass of jelly. Figure 9 shows the motion for a portion of a transient ground-vibration. It was discovered by studying [10] the vibrations around quarries that certain portions of ground could have amplitudes of vibrations greater than the rocks of the quarry in which they originated. This was noticed particularly on filled ground and suggested a certain amount of coupling between large masses of ground. The frequency in rock was higher than that of the filled ground, which fact is in agreement with the theory of coupled systems. Figûre 10 shows a field set-up at a station for measuring the three components of motion.

Experiments were conducted by the United States Bureau of Mines upon houses which were vibrated from powder-blasts until the plaster cracked and fell and the limits of safe blasting-charges were thus experimentally determined. The use of powder in such a manner as to reduce the resultant vibrations was investigated, and it was discovered that it was possible for two vibration-peaks (see Fig. 11) to cancel each other if both charges were fired simultaneously; also that by using time-delay shots (see Fig. 12) twice the charge would produce smaller vibrations than a single shot.

Later E. R. Shepard [11] made for the United States Bureau of Public Roads shallow seismic equipment capable of measuring overburden of only a few feet in depth which was used on highway-construction projects. At the present time he finds the shallow seismic refraction-work very useful for measuring the bed-rock contours at dam-sites.

Electrical prospecting--In the early experiments by the Section, most electrical prospecting was with the application of alternating potential to the ground either by direct contact or by induction. There was a distinct advantage in using alternating current because ground-contact polarization was avoided and a certain pattern of minimum potential-curves could be charted between the ground-contacts. Such curves clearly showed better and poorer conductors which might have economic significance to the extent in which they disclose a buried ore-body. The question then arose concerning the depth of such bodies, which gave rise to the iso-potential lines, and whether the skin-effect of a massive conductor, such as the ground, did not materially limit the depth of the current-penetration into the ground. Results of such tests disclosed that such iso-potential lines were of interest at the surface only and did not disclose deep-seated geologic bodies [12]. From tests made at Mammoth Cave in Kentucky upon the absorption of the electromagnetic field by rocks, in this case chiefly sandstone and limestone [13], it was found that low-frequency magnetic fields were satisfactory for depths of the order of 500 feet. The results of this work showed that a mathematical analysis of alternating ground-currents involved too many unknown factors to evaluate the elliptical polarization of the magnetic fields and that only a qualitative analysis was possible. This might give promise for finding good electrically

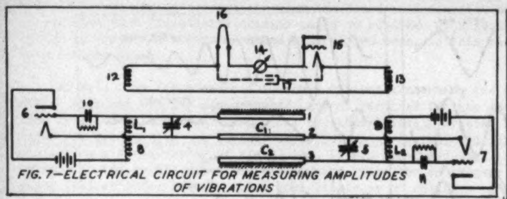


FIG. 7—ELECTRICAL CIRCUIT FOR MEASURING AMPLITUDES OF VIBRATIONS

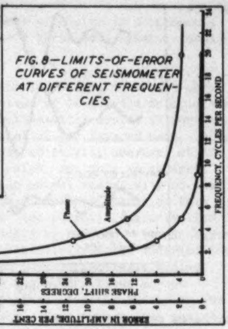


FIG. 8—LIMITS-OF-ERROR CURVES OF SEISMOMETER AT DIFFERENT FREQUENCIES

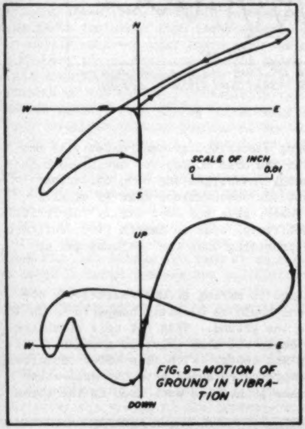


FIG. 9—MOTION OF GROUND IN VIBRATION

conducting vein-deposits as, for example, the conducting sulphides. Further studies were made using radio frequencies for shallow deposits and buried conductors [14]. Very sensitive circuits shown in Figure 13 were used which measured the change in beat-frequency of a coil owing to the proximity of ground-material which reacted back upon the main coil. Figure 14 shows the above principle carried into execution with a large amount of electrical shielding necessary for isolating the effects sought.

Self-potential methods were also tried on deposits of sulphide with good results in the Sudbury District of Canada. Unfortunately most of such effects had their origin in pyrite, which was of no economic interest in this area. A large number of tests were also made in other areas on deposits of magnetite with

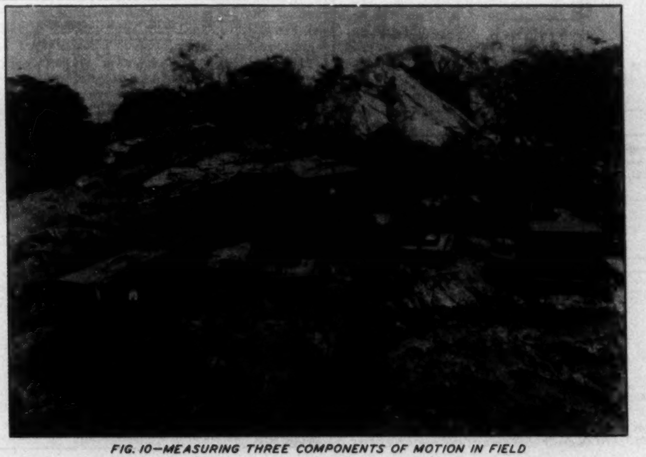


FIG. 10—MEASURING THREE COMPONENTS OF MOTION IN FIELD

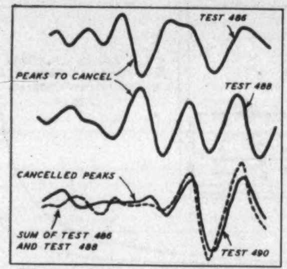


FIG. 11—CANCELLING OF TWO VIBRATION PEAKS

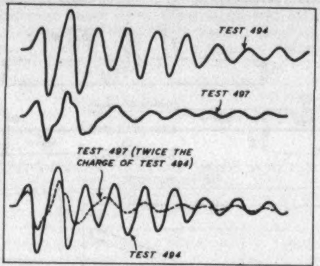


FIG. 12—USE OF TIME-DELAY FIRING FOR REDUCING VIBRATIONS FROM BLASTING

no large changes of potential.

At this time considerable interest developed in making electrical ground-resistivity measurements, and the question at first concerned itself with the best method for making such observations. The Section made a large number of experimental investigations upon different ground-configurations. The final results showed [15] that the observations made by equally spaced current- and potential-electrodes, according to Wenner, gave the most easily interpretable results at that time. Further investigations upon artificial beds by Swartz [16] confirmed the results of Rooney, and this method proved to be more promising than the Schlumberger or single-electrode method.

It was discovered that there was considerable advantage in making ground-resistivity observations in such a manner that a certain volume of ground could be directly compared to an adjacent volume without changing the electrical contacts to the ground. This not only permitted the measuring of a change of resistivity with increasing depth but also provided a means of direct comparison of adjacent material at the same location and depth. With this added technique, it was possible to determine the zone of contact of oil-impregnated sands with the salt-water boundary on shallow oil-deposits in Kentucky [17]. The same principles were used at the Abana

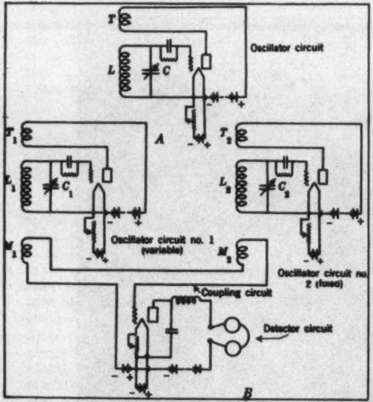

T
L
C
Oscillator circuit
A
T1
L1
C1
T2
L2
C2
M1
Oscillator circuit no. 1 (variable)
M2
Oscillator circuit no. 2 (fixed)
Coupling circuit
Detector circuit
B

FIG. 13—MEASURING CHANGES IN HEAT-FREQUENCIES DUE TO PROXIMITY OF ELECTRICAL CONDUCTORS

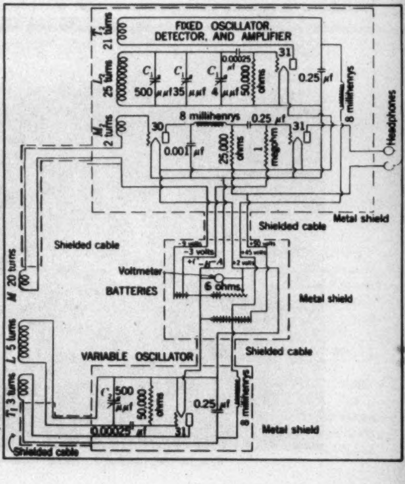

FIXED OSCILLATOR, DETECTOR, AND AMPLIFIER
T2 21 turns
L2 25 turns
C1 500 μμf
C1 135 μμf
C1 4 μμf
0.00025 μf
50,000 ohms
31
0.25 μf
8 millihenrys
M2 2 turns
30
8 millihenrys
0.25 μf
31
0.001 μf
25,000 ohms
1 megohm
Headphones
Metal shield
Shielded cable
Shielded cable
-3 volts
+45 volts
+2 volts
Voltmeter
6 ohms
BATTERIES
Metal shield
M 20 turns
L 5 turns
T1 3 turns
Shielded cable
VARIABLE OSCILLATOR
C2 500 μμf
50,000 ohms
0.25 μf
8 millihenrys
0.00025 μf
31
Metal shield
Shielded cable

FIG. 14—ACTUAL CIRCUIT AND SHIELDING EMPLOYED FOR RADIO-FREQUENCY PROSPECTING-APPARATUS

Mine [18], working in cooperation with the Canadian Geological Survey, where it was experimentally verified that resistivity-changes could be followed at a sequence of depths in a connected system of traverses across a buried mineralized zone, in this case a shear-zone running parallel to a diabase dike.

At this time there was considerable comment concerning the abrupt changes or breaks associated with resistivity-measurements, and it remained for the Section of Geophysics to secure a very detailed method of non-empirical but theoretically precise mathematical system of computations for determining the surface-distribution of current and potential for layered beds. After evaluating a large number of field-data, it was concluded that the resistivity measured at the surface of the ground was neither the exact value nor an average value, but only an apparent value [19] or index-number, which bore little or no relation to the actual resistivity of the individual beds or other geologic bodies in the ground-current field. At the moment of this writing there is no complete mathematical solution of the current- and potential-distribution in the Earth for other than the simplest condition of a single or double overburden. It was experimentally observed that there were factors other than pure ohmic resistivity which modified the current-field distribution in the Earth and which could be used to identify geologic bodies. From measurements upon nearly parallel horizontal bedded deposits there were these abrupt changes of the apparent resistivity-values which could not be explained upon the theory of the bedded layers, each having not greatly different resistivity-values. Some authorities assigned such irregularities to changes of surface-material which modified the current-flow near the surface of the ground. It was found that such was often the case, but not controlling, especially where interlocking systems of ground-measurements were made and where the same anomalies could be traced over large areas of the order of 15 square miles and along different traverses or lines of measurement over five miles long. Such was the case in Michigan, where observations were made to a depth of 1000 feet and where characteristic sequences (Fig. 15) occur which are common at many points of the area investigated. It has been postulated by the writer that these abrupt changes may be ascribed to the abrupt breaking down of electrical horizons in the ground (see Fig. 16) taking the form of an electrical double layer. Such double layers are apparently present in large numbers and could often be correlated with the contact between two adjacent beds. A sudden change of elevation of such characteristic horizons permits the recognition of buried faults as well as an accurate determination of the throw of the fault.

A careful study using earth-resistivity methods was also made in areas having steeply dipping beds covered by glaciated overburden. It was found that by measuring the anistropic component of ground-conductivity by a special arrangement of ground-contacts (Fig. 17) it was possible to determine the depth of the isotropic overburden. The superposition of the two fields (Fig. 18) shows the change of the current- and potential-field when passing from an isotropic to a non-isotropic condition. After the non-isotropic horizon has been reached, it is possible from the current-distribution pattern (Fig. 19) to determine the various up-ended beds and to trace them under the overburden and locate the cross-faulting which is often present in these areas. The area investigated comprised certain portions of the Kirkland Lake District in Northern Ontario. The results were tested by diamond drilling and underground exploration and confirmed the surface-measurements. A simple portable electrical resistivity-meter, which will measure the apparent ground-resistivity directly, has been developed as described by United States Bureau of Mines Information Circular No. 6899 and illustrated in Figure 20.

It has been necessary in many instances to correct certain popular misconceptions. One in particular was that underground water-courses act similarly to electrical conductors and have low resistivity-values. Actually the water-bearing gravels and sands have a very high resistivity and the impervious clay-beds in which they often exist have low resistivity. A large amount of research was done upon such shallow deposits of gravel in the Humboldt Valley near Lovelock, Nevada, and their economic importance has not been altogether discounted. Also a certain amount of research was done upon deep aquifers which carry artesian water in certain districts of Nevada.

Gravimetric work--The Section of Geophysics had recognized from the start the great value of gravimetric measurements for determining the location and form of buried geologic bodies as well as structural modifications associated with them. It was convinced that such measurements using a torsion-balance were entirely inadequate as well as too expensive for making gravimetric surveys. In order to aid the preparation of torsion-balance field-data for purposes of interpretation, the Section issued a technical paper by Barton [20] describing the corrections necessary for terrane as well as a graphical method for evaluating them. It clearly recognized the necessity of research especially upon the precision-measurement of small angles to an accuracy in the seventh significant figure. The gravimeter or gravity-variometer has substantiated the above course of development, whose progress has been retarded owing to lack of funds.

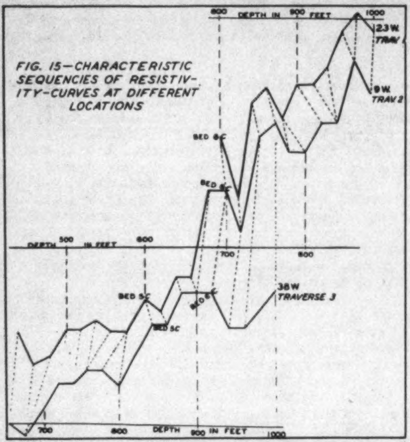
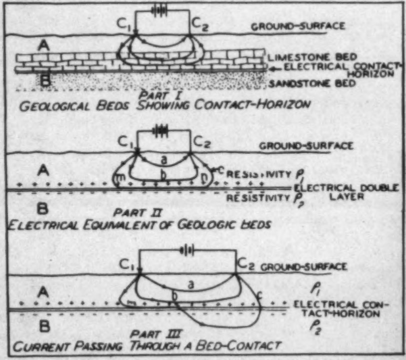


FIG. 15—CHARACTERISTIC SEQUENCIES OF RESISTIVITY-CURVES AT DIFFERENT LOCATIONS


C1
C2
GROUND-SURFACE
A
LIMESTONE BED
ELECTRICAL CONTACT-HORIZON
B
SANDSTONE BED
C1
C2
GROUND-SURFACE
A
a
m
b
n
c
RESISTIVITY ρ1
ELECTRICAL DOUBLE LAYER
RESISTIVITY ρ2
B
C1
C2 GROUND-SURFACE
A
a
b
c
m
ρ1
ELECTRICAL CONTACT-HORIZON
B
ρ2

PART I
GEOLOGICAL BEDS SHOWING CONTACT-HORIZON

PART II
ELECTRICAL EQUIVALENT OF GEOLOGIC BEDS

PART III
CURRENT PASSING THROUGH A BED-CONTACT

FIG. 16—ELECTRICAL HORIZONS IN GROUND

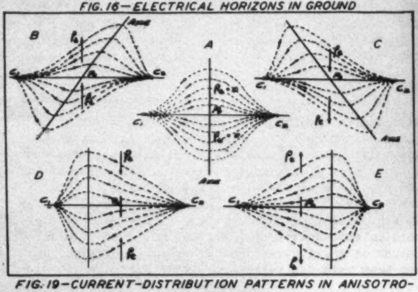

B
A
C
D
E
C1
C2
Axis
Axis
Axis

FIG. 19—CURRENT-DISTRIBUTION PATTERNS IN ANISOTROPIC MEDIA

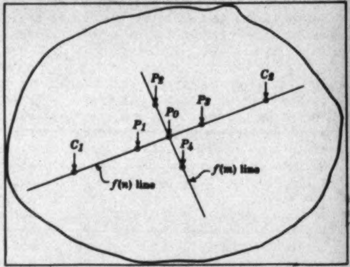

P2
C2
P3
P0
P1
C1
P4
f(n) line
f(m) line

FIG. 17—CONFIGURATION OF GROUND-CONTACTS FOR MEASURING THE ANISOTROPIC RESISTIVITY-COMPONENT

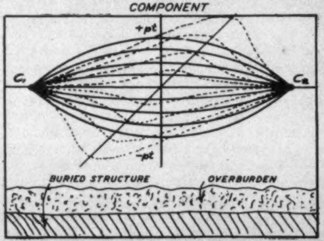

+pt
C1
C2
-pt
BURIED STRUCTURE
OVERBURDEN

FIG. 18—SUPERPOSITION OF AN ISOTROPIC CONDITION UNDERLAIN BY AN ANISOTROPIC ONE (FIELD DUE TO OVERBURDEN——— : TO BURIED STRUCTURE---)

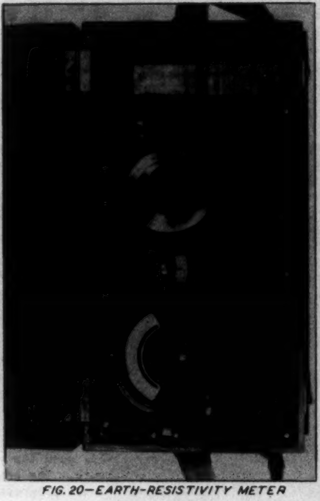


FIG. 20—EARTH-RESISTIVITY METER

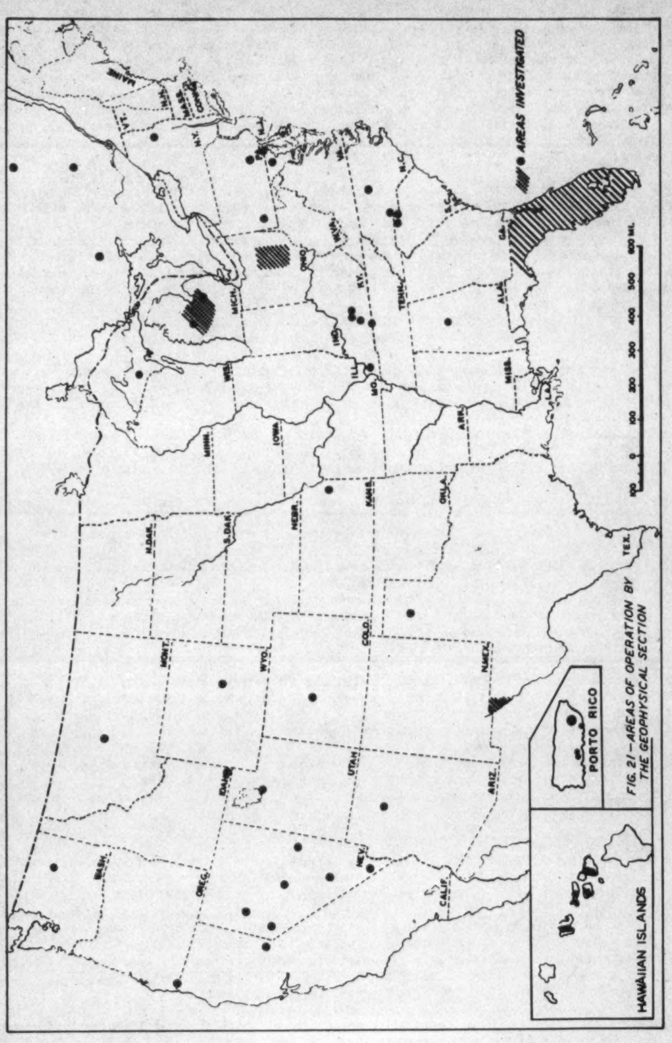

▨ ● AREAS INVESTIGATED
100 0 100 200 300 400 500 600 MI.
PORTO RICO
HAWAIIAN ISLANDS
MAINE
VT.
N.H.
MASS.
CONN.
N.Y.
N.J.
VA.
N.C.
S.C.
GA.
FLA.
ALA.
MISS.
LA.
TENN.
KY.
W.VA.
OHIO
MICH.
IND.
ILL.
WIS.
MINN.
IOWA
MO.
ARK.
OKLA.
KANS.
NEBR.
S.DAK.
N.DAK.
MONT.
WYO.
COLO.
N.MEX.
TEX.
UTAH
ARIZ.
IDAHO
NEV.
CALIF.
OREG.
WASH.

FIG. 21—AREAS OF OPERATION BY THE GEOPHYSICAL SECTION

*Areas of operation*--The areas in which work has been done are shown in Figure 21. Their selection has been controlled by many factors. Sometimes it has been desirable to test a geophysical principle, and geological conditions have been selected favorable for such tests. At other times requests have been made concerning the adaptability or usefulness of geophysical methods in certain areas or districts. Then there have been emergency calls for the investigation of drought areas or of city wells contaminated by salt water. The loss of ore-veins by cross-faulting has received careful consideration, and major geologic problems not bearing directly upon economic exploitation are receiving careful consideration at the present time. Water-problems of very diverse natures have occupied the Section for a long time and are becoming increasingly important.

*Comments*--Although the practical application of geophysics, with few exceptions, can not give a complete answer to geologic problems, there is seldom a situation in which the additional light thrown upon the problem by its use does not greatly clarify the interpretation. The answer to most economic problems in the search for ore-bodies will find its solution after the general geologic problems have been evaluated. A very careful fundamental geophysical research, as complete in its scope as a comparable geological examination of the same area, embracing a combined and more complete picture of an area, is the best approach to mineral exploitation.

### List of publications on geophysical prospecting issued by the Bureau of Mines, United States Department of the Interior

[1] Technical Paper 420, Geophysical methods of prospecting, a brief and elementary account of the principles involved, by A. S. Eve and D. A. Keys, 1927, 26 pp.

[2] Technical Paper 434, Geophysical prospecting: Some electrical methods, by A. S. Eve and D. A. Keys, 1928, 41 pp.

[3] Technical Paper 439, Geophysical investigations of the United States Bureau of Mines at Caribou, Colorado, by C. A. Heiland, C. W. Henderson, and J. A. Malkovsky, 1929, 45 pp.

[4] Technical Paper 440, Measuring the variation of ground-resistivity with a Megger, by F. W. Lee, 1928, 16 pp.

[5] Technical Paper 444, Graphical terrane correction for gravity gradient, by D. C. Barton, 1929, 10 pp.

[6] Technical Paper 463, Depth attainable by electrical methods in applied geophysics, by A. S. Eve, D. A. Keys, and F. W. Lee, 1929, 58 pp.

[7] Technical Paper 488, Resistivity measurements of oil-bearing beds, by F. W. Lee and J. H. Swartz, 1931, 12 pp.

[8] Technical Paper 497, Electromagnetic absorption by rocks, with some experimental observations taken at the Mammoth Cave of Kentucky, by J. W. Joyce, 1931, 28 pp.

[9] Technical Paper 501, Results of electrical resistivity and electrical-induction measurements at Abana Mine, Quebec, Canada, by E. V. Potter, with explanation of some factors associated with induction method, by F. W. Lee, 1931, 28 pp.

[10] Technical Paper 502, How to compute tables for determining electrical resistivity of underlying beds and their application to geophysical problems, by Irwin Roman, 1931, 44 pp.

[11] Technical Paper 510, Results of some magnetic measurements on dikes, with experiments upon geophysical differentiation of nickel-ore deposits in the Sudbury District, Ontario, Canada, by F. W. Lee, 1932, 18 pp.

[12] Technical Paper 518, Construction of master mechanical oscillator for testing seismic recorders and other allied apparatus, by F. W. Lee and G. A. Irland, 1932, 17 pp.

[13] Technical Paper 521, Oil prospecting in Kentucky by resistivity methods, by J. H. Swartz, 1932, 23 pp.

[14] Technical Paper 528, A magnetic study of some iron deposits, by E. F. Stratton and J. W. Joyce, 1932, 32 pp.

[15] Technical Paper 546, Theory of torsion balance, with preliminary study of modification of instrument to decrease time of gravity measurements, by J. W. Joyce, 1933, 46 pp.

[16] Technical Paper 556, A study of some seismometers, by G. A. Irland, 1934, 48 pp.

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[18] Information Circular 6141, Tentative method for making resistivity measurement of drill cores and hand specimens of rocks and ores, by M. W. Pullen, 1929, 10 pp.

[19] Information Circular 6171, Some earth resistivity measurements, by F. W. Lee, J. W. Joyce, and Phil Boyer, 1929, 16 pp.

[20] Information Circular 6235, Comparative advantages of applying several geophysical methods of prospecting to the same territory, by F. W. Lee, 1930, 11 pp.

[21] Information Circular 6306, Nomographs for calculating the second derivatives of the force of gravity potential obtained by observations made with a torsion balance at five azimuths, by W. Ayvazoglou, translated from the original Russian of A. Stepanoff, 1930, 5 pp.

[22] Information Circular 6445, Resistivity measurements upon artificial beds, by J. H. Swartz, 1931, 9 pp.
[23] Information Circular 6496, A comment upon present-day geophysics, by F. W. Lee, 1931, 5 pp.
[24] Information Circular 6527, Practical rules for the use of magnetometer in geophysical prospecting. Translated by W. Ayvazoglou from the original French of M. C. Alexanian, 1931, 19 pp.
[25] Information Circular 6854, Induction prospecting for shallow ore deposits and small metallic objects, by J. W. Joyce, 1935, 18 pp.
[26] Information Circular 6883, Patents on geophysical prospecting issued in the United States, England, Canada, Australia, Germany, France, and Russia, by W. Ayvazoglou, 1936, 136 pp.
[27] Information Circular 6899, Geophysical prospecting for underground waters in desert areas, by F. W. Lee, 1936, 27 pp.
[28] Report of Investigations 3319, Earth vibrations caused by quarry blasting, by F. W. Lee, J. R. Thoenen, and Stephen L. Windes, 1936, 19 pp.
[29] Report of Investigations 3353, Earth vibrations caused by quarry blasting, by J. R. Thoenen and Stephen L. Windes, 1937, 73 pp. Progress Report 1.
[30] Manual on geophysical prospecting with the magnetometer, by J. W. Joyce [Bur. Mines, U. S. Dept. Int., 1937, 129 pp.].
[31] Geophysical Abstracts, issued monthly by the Bureau of Mines prior to July 1, 1936, and now being published quarterly by the Geological Survey.

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[1] A. S. Eve and D. A. Keys, Geophysical methods of prospecting: A brief and elementary account of the principles involved, Bur. Mines, Tech. Pap. 420, 1927, 26 pp.
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[4] E. F. Stratton and J. W. Joyce, A magnetic study of some iron deposits, Bur. Mines, Tech. Pap. 528, 1932, 32 pp.
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[11] E. R. Shepard, Subsurface exploration by earth resistivity and seismic methods, U. S. Dept. Agric., Public Roads, v. 16, No. 4, June, 1935.
[12] A. S. Eve, D. A. Keys, and F. W. Lee, Depth attainable by electrical methods in applied geophysics, Bur. Mines, Tech. Pap. 463, 1929, 58 pp.
[13] J. W. Joyce, Electromagnetic absorption by rocks, with some experimental observations taken at the Mammoth Cave of Kentucky, Bur. Mines, Tech. Pap. 497, 1931, 28 pp.
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[16] J. H. Swartz, Resistivity measurements upon artificial beds, Bur. Mines, Information Circ. 6445, 1931, 9 pp.
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[20] D. C. Barton, Graphical terrane correction for gravity gradient, Bur. Mines, Tech. Pap. 444, 1929, 10 pp.

U. S. Geological Survey,
Washington, D. C.

## PART II--GEOPHYSICAL INVESTIGATIONS IN THE HAWAIIAN ISLANDS

J. H. Swartz

(Published with the approval of the Director, U. S. Geological Survey)

During 1938 and 1939, an extensive series of geophysical surveys, employing both resistivity and magnetic methods, have been carried on in the Hawaiian Islands by the Section of Geophysics of the United States Geological Survey in cooperation with the Division of Ground-Water of the Survey and the Division of Hydrography of the Territorial Government (see Fig. 1). During this time, surveys have been conducted on the islands of Oahu, Molokai, and Maui. Two distinct types of ground-water occurrence are being investigated: (1) The basal fresh-water lens floating on underlying salt water in obedience to the Ghyben-Herzberg principle (Fig. 2); and (2) perched ground-water (Fig. 3).

### Oahu surveys

Schofield Plateau Area--An area of over 120 square miles, lying between Waimea Bay on the northeast, Waialua on the northwest, Ewa on the southwest, and Aiea on the southeast, was surveyed by resistivity-methods during the first part of 1938, as seen in Figure 4. The purpose of the survey was twofold: (1) To outline the approximate area underlain by the high-level basal fresh-water discovered in the Schofield shaft near Wahiawa; and (2) to determine the general basal water-table elevations underlying the isthmian area between the Koolau Mountains on the east and the Waianae Range on the west. These two problems are of importance in planning the future development of basal fresh-water supplies for

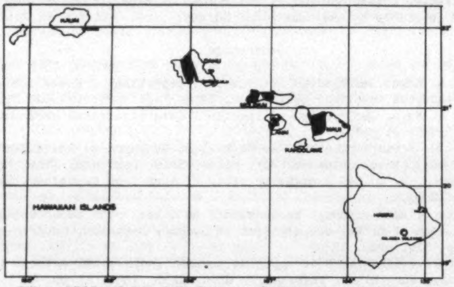


FIG. 1—GEOPHYSICAL SURVEYS IN HAWAIIAN ISLANDS SHOWN IN BLACK, SECTION OF GEOPHYSICS, U.S. GEOLOGICAL SURVEY

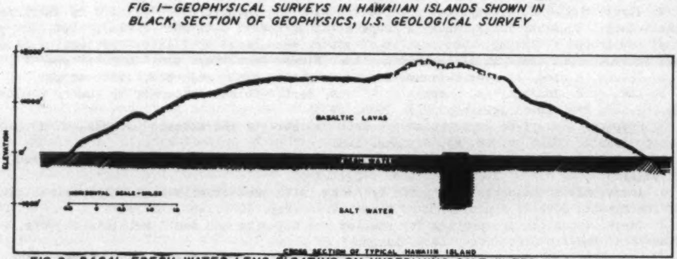


FIG. 2—BASAL FRESH-WATER LENS FLOATING ON UNDERLYING SALT-WATER IN OBEDIENCE TO GHYBEN-HERZBERG PRINCIPLE

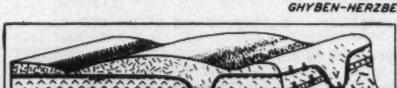


FIG. 3—DIAGRAM ILLUSTRATING SOME TYPICAL MODES OF OCCURRENCE OF PERCHED GROUND-WATER IN HAWAIIAN ISLANDS

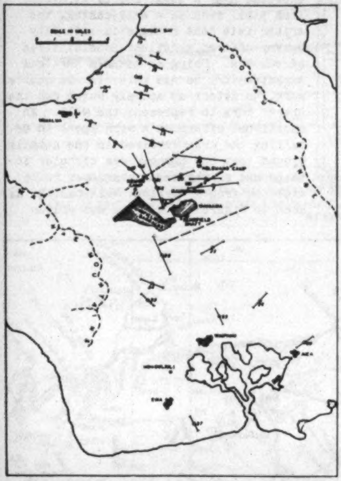


*FIG. 4—MAP OF SCHOFIELD PLATEAU AREA OF OAHU SHOWING LOCATION OF RESISTIVITY-STATIONS (AREA UNDERLAIN BY HIGH-LEVEL BASAL WATER IS DEMARCATED BY BROKEN LINES)*

the sugar and pineapple plantations of the isthmian area and in selecting the most desirable locations, from the standpoint of water-supply for projected camps.

Considerable difficulty was encountered in planning the survey and running the measurements due to the extensive agricultural cultivation of the Schofield Plateau Area, the absence of long straight roads, and the presence of numerous pipelines, railroad tracks, lead-sheathed communication-cables, and other grounded conductors which would distort the electric fields involved in the measurements. Despite these interfering factors, 32 stations were occupied and measurements run to depths up to 6000 feet below the surface or 5100 feet below sea-level (Fig. 5).

It was found that the area underlain by the high-level basal fresh-water discovered in the Schofield Shaft extended but a short distance to the south of the Shaft, having disappeared before Kipapa Junction is reached, as seen in Figure 4. North of the Schofield Shaft, the basal fresh-water lens has a thickness of 4000 or more feet and water-table elevation of 100 feet or more over an area extending almost as far north as Kaukonahua Camp, about a mile north of Wahiawa. A transition-zone, within which the basal lens decreases from 4000 feet to a normal thickness of 800 to 1000 feet, extends from Kaukonahua Camp to near Kemoo Farm. The zone of basal water of level higher than normal thus extends for a distance of about four miles in a north-south direction. To the east, the zone of high-level water extends at least as far as Helemano Camp and to the west as far as Schofield Barracks. The total area underlain by high-level basal fresh-water is thus around 16 square miles, possibly more. To the north and south of the high-level water-area, basal fresh-water of normal low level extends to the coast. The minimum water-table elevation, one-half foot, was found near Waimea Bay on the northeast.

Location of lost artesian wells--Defective casings and leaky wells cause serious loss of artesian water in the various artesian basins on Oahu. It is one of the duties of the Chief Hydrographer of the Territory to see that such leaking wells are repaired or sealed to prevent further loss of artesian water. Many of the older wells have been covered up and their exact locations forgotten, so that it has been impossible to find them.

When the writer reached Honolulu in February, 1938, he was asked whether he could locate such lost wells by geophysical methods. In particular, it was desired to locate the "Pioneer Well," drilled near the village of Honouliuli in 1879, the first well drilled in the Islands. This Well was known to lie near the Ewa Road but had been sought for two years without success. Just before the writer's arrival, some $500 had been spent by the City and County of Honolulu in digging a large pit at a spot where it was thought that the Well had been located, but it had not been found.

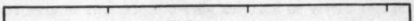


*FIG. 5—RESISTIVITY-CURVES AT STATION 31, OAHU; THESE MEASUREMENTS ARE DEEPEST SO FAR MADE IN COURSE OF A ROUTINE RESISTIVITY-SURVEY, HAVING REACHED DEPTH 6000 FEET (5088 FEET BELOW SEA-LEVEL)*

In view of the marked distortion in the Earth's magnetic field which is to be

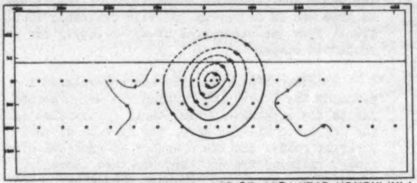


FIG. 6—MAGNETIC ISANOMALY MAP OF AREA NEAR HONOULIULI, OAHU, SHOWING CONCENTRIC ISOGAM-CONTOURS BY WHICH LOST PIONEER WELL WAS FOUND

expected near a long, nearly vertical, iron pipe, such as a well-casing, the writer felt that a magnetic-intensity survey offered excellent possibilities of success. Using an Askania vertical magnetometer, he was able, in one hour's work, to detect an anomaly which had the proper form to represent the Well. An additional afternoon's work spent in detailing the area involved in the anomaly proved that the anomaly was circular in shape and of the exact character to be expected from a vertical well-casing, as seen in Figure 6. A stake was driven into the ground at the center of the anomaly to mark the position of the Well. Some six months later, a pit was dug at the spot marked by the stake. The Well was found under the stake at a depth of approximately 12 feet. Following this first success, a considerable number of such lost wells have been located.

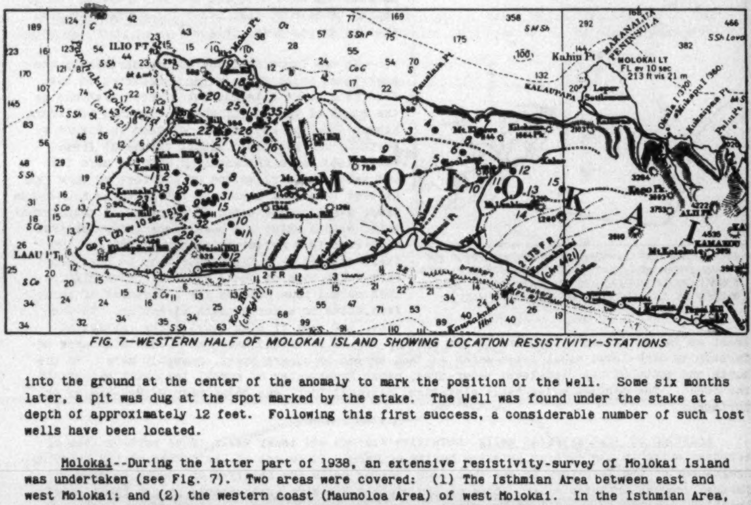


FIG. 7—WESTERN HALF OF MOLOKAI ISLAND SHOWING LOCATION RESISTIVITY-STATIONS

Molokai--During the latter part of 1938, an extensive resistivity-survey of Molokai Island was undertaken (see Fig. 7). Two areas were covered: (1) The Isthmian Area between east and west Molokai; and (2) the western coast (Maunoloa Area) of west Molokai. In the Isthmian Area, 15 stations were occupied and an area of approximately 35 square miles was covered. On the Maunoloa Coast, 35 stations were occupied and an area of 45 square miles was covered. Thus during the survey 50 stations were occupied and an area of approximately 80 square miles was covered.

The purpose of the survey was to determine the heights of the basal fresh-water table throughout the areas studied. It was desired: (1) To find the height of the water-table, the thickness of the basal fresh-water lens, and the depth to salt water at certain projected Maui County water-development sites as well as along the course of the new water-tunnel from East Molokai to be constructed under Federal aid; and (2) to determine whether there were any areas on the Isthmus or on west Molokai underlain by high-level basal fresh-water.

While studies of the data obtained from the resistivity-measurements are not yet complete, the geophysical survey has shown: (1) There is no high-level basal water in the

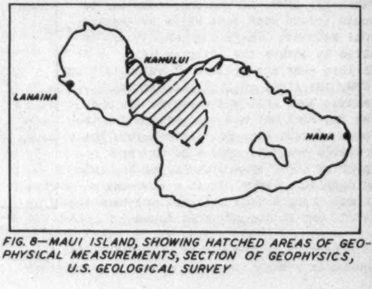


FIG. 8—MAUI ISLAND, SHOWING HATCHED AREAS OF GEOPHYSICAL MEASUREMENTS, SECTION OF GEOPHYSICS, U.S. GEOLOGICAL SURVEY

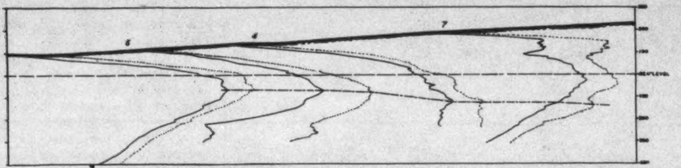


FIG. 9—RESISTIVITY-CURVES PUKULANI ROAD TRAVERSE, WHICH GAVE FIRST CLUE TO TECHNIQUE FOR DETERMINING DEPTH TO SALT-WATER AND HEIGHT AND THICKNESS OF BASAL FRESH-WATER LENS IN THE HAWAIIAN ISLANDS (DASH-DOT LINE CONNECTS SALT-WATER BREAK ON SUCCESSIVE RESISTIVITY-CURVES)

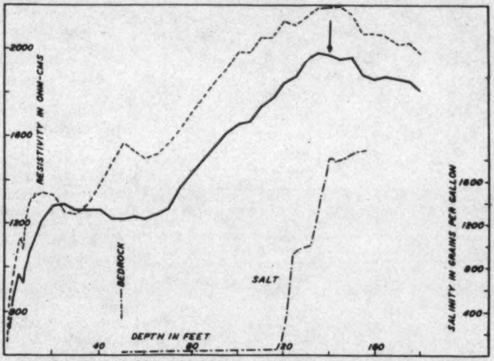


FIG. 10—COMPARISON RESISTIVITY-CURVES MEASURED AT KAHULUI FAIR GROUNDS, MAUI, WITH SALINITY-CURVE OF WATER IN DIAMOND DRILL-HOLE LATER DRILLED THERE (ARROW REPRESENTS THE SALT-WATER BREAK IN RESISTIVITY-CURVES)

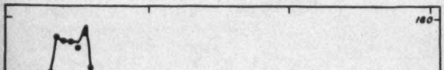


FIG. 11—CURVES SHOWING ACCURACY RESISTIVITY-MEASUREMENTS, NEW RESISTIVITY-APPARATUS UNDER OPERATION IN AREA OF ANNUAL RAINFALL 280 INCHES (SOLID LINE REPRESENTS ORIGINAL MEASUREMENT AT STATION 45, AND CIRCLES REPRESENT LATER REPEAT-MEASUREMENT AT SAME STATION)

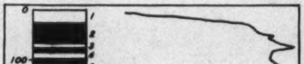
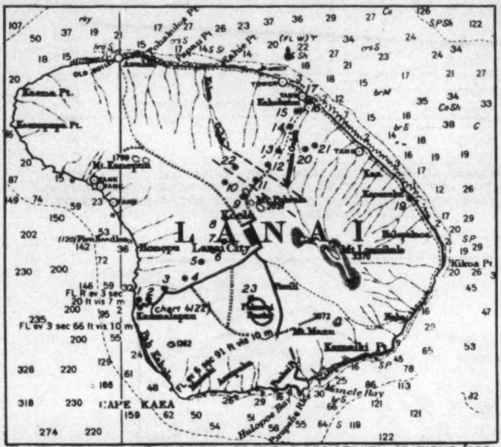


FIG. 12—COMPARISON RESISTIVITY-CURVE AT DIAMOND DRILL-HOLE 40, HANAWI, UPPER NAHIKU, MAUI, WITH DIAMOND DRILL-LOG (BLACKENED BEDS REPRESENT SOIL OR WEATHERED HORIZONS)


L A N A I
Lanai City
Kaena Pt.
Mt. Kanepuu
Honopu
Kaumalapau
CAPE KAEA
Hulopoe Bay
Manele Bay
Kamaiki Pt.
Kikoa Pt
3370
2072
1780
FL R ev 3 sec 20 ft vis 7 m
FL ev 3 sec 66 ft vis 10 m
(chart 4122)
TANK
TOWER
SP
SPSh
CoSh
brS
crsS
107
50
37
19
21
17
27
26
23
37
36
29
27
126
122
24
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62
64
66
150
159
202
230
200
235
328
220
318
274
142
146
59
74
87
149
72
36
32
2
95
55
129
188
61
48
24

FIG. 13—LANAI ISLAND, SHOWING LOCATIONS RESISTIVITY-STATIONS (BROKEN LINES SHOW APPROXIMATE BOUNDARIES AREA UNDERLAIN BY HIGH-LEVEL BASAL WATER DISCOVERED BY RESISTIVITY-SURVEY)

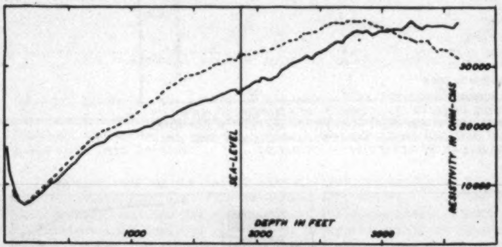

FIG. 14—RESISTIVITY-CURVES WHOSE DEEP SALT-WATER BREAK, AT 2820 FEET, FIRST PROVED PRESENCE OF HIGH-LEVEL BASAL FRESH-WATER ON LANAI ISLAND

Isthmian Area; (2) the basal water-table on the southern flank of the Isthmus is very low, so that a considerable salinity may be expected in water developed there; (3) the basal water-table is approximately some three to five times higher on the northern flank of the Isthmus than on the southern flank; (4) some basal water of considerably higher level is to be found along the ridges leading to the northern and southern angles of the west Maunoloa Coast; (5) elsewhere in the Maunoloa Area the water-table levels are much like those on the south flank of the Isthmus.

### Maui surveys

On Maui Island (see Fig. 8), geophysical surveys are being made in two separate areas and on two distinct problems: (1) In the Maui Isthmus, where the basal fresh-water lens is being investigated; and (2) in east Maui, where a research study is being made of the perched ground-water problem.

Maui Isthmus Area--The initial studies of the application of resistivity-measurements to basal fresh-water lens problems were made in the Maui Isthmus Area in 1936. It was here that the technique for making determinations of the depth to salt water, the thickness of the basal fresh-water lens, and the height of the basal water-table was developed (see Fig. 9). Here also, at the Kahului Fair Grounds, the first drilling test (Fig. 10) was made of the validity of the resistivity-methods for the solution of basal water-problems. This test proved so successful that the use of resistivity-methods was immediately extended to other islands which had pressing basal-water problems. The present survey constitutes a continuation and extension of the original Maui Isthmus survey. Special attention is being paid to the character of the changes in the basal fresh-water lens in passing from the Isthmus floor up the flanks of the adjoining West Maui Mountains on the west end of Haleakala on the east.

This survey is still in progress so that a report of results can not yet be made. However, the work so far completed shows a definite increase in the depths to salt water, the thickness of the basal fresh-water lens, and the heights of the basal water-table in ascending the west slope of Haleakala. It further has shown a considerable stratigraphic complexity in the lavas underlying Haleakala's western flank, with great variations in the porosities of the different flows. These variations complicate somewhat the basal water-relationships. In some localities, the position of the water-table, or of the top of the salt water, is occupied by dense impermeable lavas, as is shown by the characteristics of the resistivity-curves there obtained.

East Maui Area--The investigation of the East Maui Area was likewise initiated in 1936. The heavy rainfall, approximately 280 inches per year in the area under survey, introduced numerous difficulties which had to be overcome by the design and development of new types of resistivity-apparatus and equipment (Cf. Fig. 11). Such new apparatus was completed in 1937 and the resistivity-survey resumed in 1938.

The problem in the East Maui Area is to develop a technique by means of which ground-water perching horizons, such as ash-beds and soil-horizons representing old erosion-surfaces, can be detected and traced from one position to another. A check of resistivity-measurements against the log of a diamond-drill hole has demonstrated a close correlation between certain breaks in the resistivity-curve and various lava-flows and soil-horizons found in the drill-core (see Fig. 12). The solution of this problem involves the development of methods by which the effect of lateral changes in a single flow, or lateral breaks due to buried valleys, water-falls, etc., can be differentiated from the effects of the vertical changes between successive lava-flows. The problem has proved a very difficult one involving extensive research. Methods have been developed for differentiating between such vertical and horizontal effects and are now being applied in the East Maui Area.

### Lanai surveys

No resistivity-measurements have been made on Lanai Island since the completion of the geophysical survey there in 1936 (Fig. 13). However, some of the results of that survey have recently been tested. Following the discovery by the resistivity-measurements of high-level basal fresh-water near the crest of the Island (see Fig. 14), a water-development shaft was begun in Maunalei Valley at a location selected on the basis of the resistivity-measurements as lying in the high-level water-area. The shaft encountered high-level water at an elevation of 735 feet above sea-level.

### Summary

Geophysical surveys in the Hawaiian Islands have been completed, or are in progress, in the following areas, for the following purposes:

(I) Oahu
- (A) Schofield Plateau Area: Location and outline of the area underlain by high-level basal water and determinations of the depth to salt water, the thickness of the basal fresh-water lens, and the elevations of the basal water-table.
- (B) Lost wells: Location of artesian wells whose positions have been lost through burial, loss of markers, etc.

(II) Molokai
- (A) Isthmus Area: Determinations of depths to salt water, thickness of the basal fresh-water lens, and the elevations of the basal water-table.
- (B) Maunoloa Area: Determinations of depths to salt water, thickness of the basal fresh-water lens, and elevations of the basal water-table; location of areas of higher-level basal fresh-water.

(III) Maui
- (A) Isthmus Area: Determinations of depths to salt water, thickness of the basal fresh-water lens, and elevations of the basal water-table (investigation continuing).
- (B) East Maui Area: Investigations in connection with the problem of perched ground-water including: Design and construction of special apparatus and equipment; working out of new types of methods and new resistivity-techniques for the identification of perching horizons such as ash-beds and old soil-horizons, for the separation of vertical and horizontal stratigraphic effects, and for the detection of buried, lava-filled valleys. A series of different lava-flows found in a diamond-drill hole have been identified by characteristic changes in the resistivity-curves; these horizons are being traced from a known into unknown areas (investigation continuing).

(IV) Lanai

Determination of depths to salt water, thickness of the basal fresh-water lens, and elevations of the basal water-table. A zone of high-level basal water was discovered by the resistivity-measurements. A recent water-development shaft, sunk on the basis of the resistivity-measurements, encountered the high-level water as predicted by these measurements.

Two hundred and thirty stations, ranging in depth from 26 feet to 6000 feet, penetrating to depths up to 5100 feet below sea-level, and covering an area of approximately 360 square miles, have been run in the Hawaiian Islands to date. Thus far, quantitative tests of water-table heights, as predicted by the resistivity-measurements, have been possible at only five water-development sites (two shafts, three drill-holes, and one well). The predicted heights have agreed with the observed heights within an average value of 0.56 foot, the individual differences between observed and predicted results ranging from 1.1 feet to 0.03 foot.

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## PART III--FUNDAMENTAL RESEARCH IN GEOPHYSICS RELATING TO PROSPECTING

Irwin Roman
(Published with the approval of the Director, U. S. Geological Survey)

In addition to projects such as those reported in parts I and II above, the Section of Geophysics of the Federal Government has undertaken a considerable amount of fundamental research.

Two such field-projects may be mentioned, one a magnetometric study in the Comstock District of Nevada, and the other a resistivity-study of snow and ice. In addition to the field-problems, there have been two classes of research of a mathematical type. One of these has been the preparation of tables, scales, and charts for the important geophysical functions already known; the other has been the extension of the relations involved in the resistivity-problem.

The magnetometric study at Spring Valley, in the Comstock District, was made for the purpose of determining the value of the magnetometer in extending the knowledge of a region, as obtained by purely geological means. The variations in the vertical magnetic intensity were measured with an Askania balance at intervals of 20 feet, along lines as shown in Figure 1. These lines were 100 or 500 feet apart over an area approximately a rectangle 6000 by 7500 feet. In addition to the lines shown, two areas were selected for more intensive study. In one, short

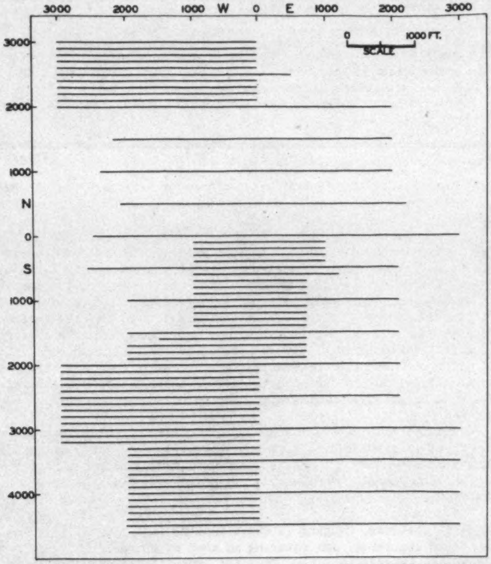

FIG. 1—SPRING VALLEY AREA, NEVADA, MAGNETOMETRIC STUDY

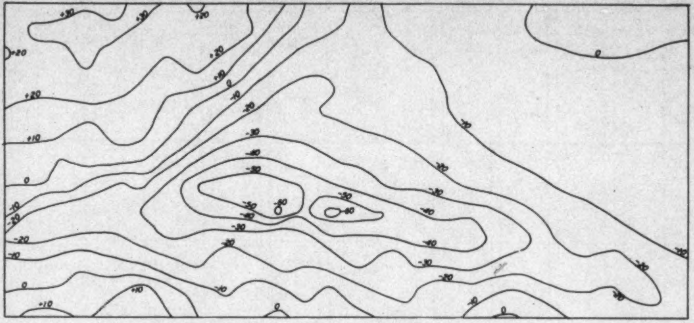

FIG. 2—ISOGAM-MAP IN SPRING VALLEY AREA

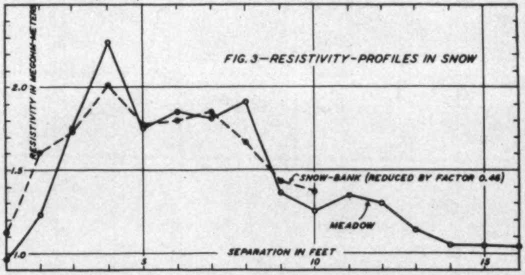

FIG. 3—RESISTIVITY-PROFILES IN SNOW

lines were run between the 100-foot lines to study the transverse variations. A rectangular grid, about 140 by 400 feet, was run in the other on a 20-foot spacing both ways. Measurements over a known gold-bearing vein of quartz had shown a definite low. One of the 500-foot lines had shown another low of considerable size, suggesting the grid. The results are shown in the isogam map of Figure 2, in which the contour-figures represent scale-divisions from an arbitrary base-point. The range of vertical intensities is about 3000 gammas. In another portion of the region, values of about 5000 gammas above the base-value were found and traced to the presence of epidote containing magnetite.

The study of the resistivity of snow and ice in place was made independently at Soda Springs, California [see 1 of "References" at end of paper], at an altitude of about 7000 feet in the High Sierras, and at a point in the Appalachians near Pittsburgh, Pennsylvania [2]. The methods differ in details, but the results are in good agreement. Figure 3 shows the results for two locations, one along the load in the Sierras, where the snow had been thrown by the road-clearing machines, and the other in a flat meadow. The resistivity of snow was found to be very close to that of distilled water.

Of the various mathematical functions, two were selected for tabulating. The first table constructed was that of the three-halves powers of the integers from 1 to 1000 and of ten times these numbers. These have been computed to ten significant figures. An auxiliary table makes possible the interpolation for two additional figures in the argument. The two-thirds powers have been calculated for the integers from 1 to 250, multiples of 10 from 250 to 500, and multiples of 100 from 500 to 5000. These have also been calculated to ten significant figures. In isolated cases, the calculation of these powers furnishes no great difficulties, but in repeated use, the tables have demonstrated their usefulness.

The second function selected for tabulating was that encountered in calculating the compo-

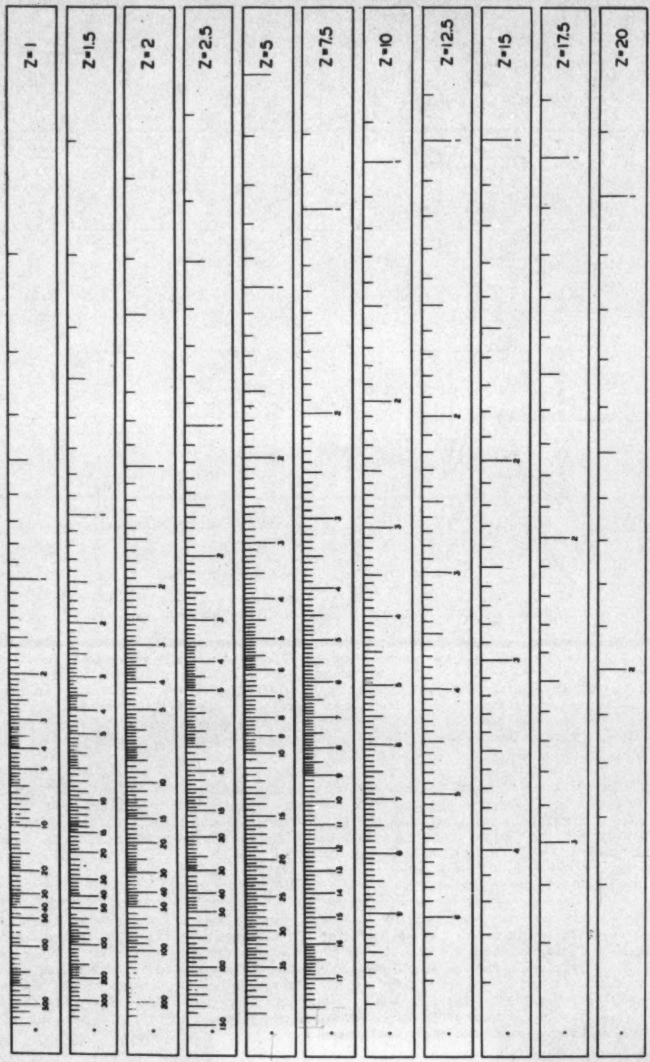
Z=1
Z=1.5
Z=2
Z=2.5
Z=5
Z=7.5
Z=10
Z=12.5
Z=15
Z=17.5
Z=20

FIG. 4—SCALES FOR EVALUATING COMPONENTS

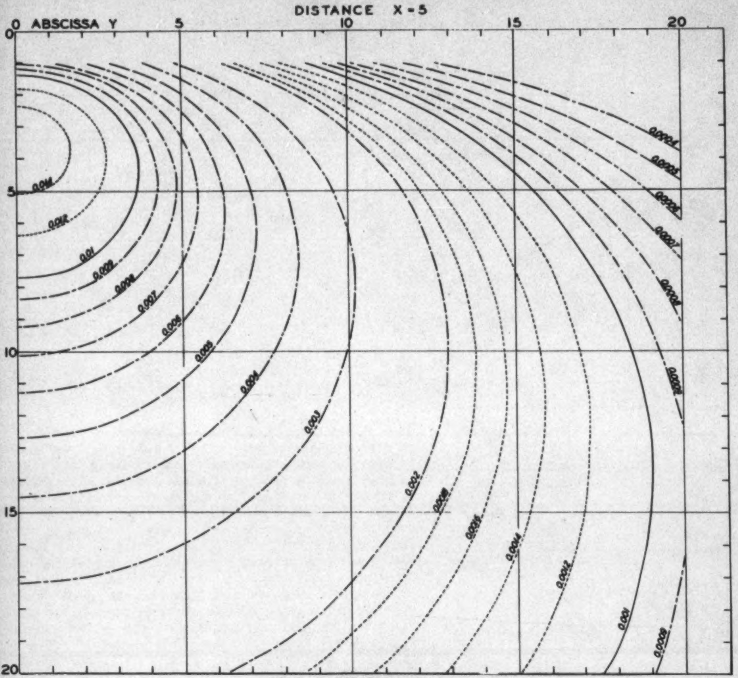

FIG. 5—CHART FOR DISTANCE 5

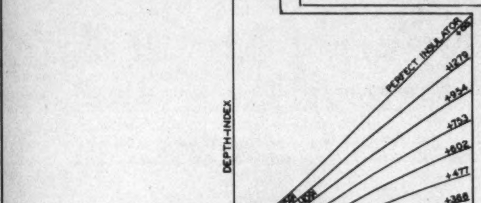

FIG. 6—APPARENT RESISTIVITIES FOR A BURIED INSULATOR

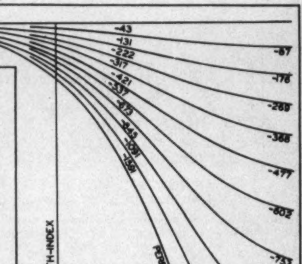

FIG. 7—APPARENT RESISTIVITIES FOR A BURIED CONDUCTOR

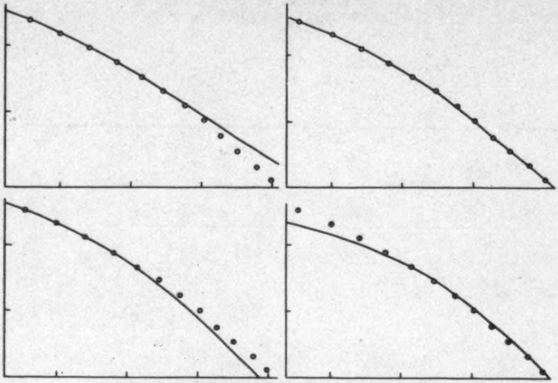

*FIG. 8—CURVES SUPERPOSED ON OBSERVED DATA*

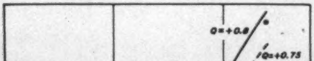

*FIG. 9—AN OBSERVED CURVE FITTED BETWEEN TWO STANDARD CURVES*

nent of a force. This function is $v = z/r^3$ where $r^2 = x^2 + y^2 + z^2$. Before this function had been calculated for many arguments, it was realized that the results could be reduced to simple scales. Three-place calculations were made for numerous combinations of x, y, and z. A more elaborate set of calculations has been in progress during the past year through the cooperation of the Department of Justice. Two young men at one of the Federal penitentiaries have substituted calculations on this function for part of their educational training. Each has been furnished with a modern electrical computing machine and with forms for evaluating the function to eight decimal places for integral values of x, y, and z. At present, values of z from 1 to 50 have been used for x = 0, and x = 1, and values of y from 0 to about 40.

The use of scales for determining the components of force has been discussed elsewhere [3]. With these scales, used very simply, the effects of assumed geologic bodies may be obtained for a selected station with very little calculation. Irregular bodies may be studied as easily as regular ones. By starting with as good an approximation as possible from the field-results, the predicted profiles may be calculated and the assumed body or structure modified according to the differences between the predicted and observed values. By successive corrections, an anomalous body can be determined which will reproduce the observed intensities, whether magnetic or gravimetric. The scales can also be used for other problems. The scales show the component perpendicular to the plane in which the anomalous body is contoured.

To determine the effects parallel to the plane of sectioning, charts have been constructed. The method of use is similar to that for the scales. With these scales and charts, experience will lead to a set of reference-curves for different types of anomalous bodies.

Figure 4 shows typical scales selected from the set already constructed. This set contains scales for the multiples of a half from 1 to 23.

Figure 5 shows the chart for a distance of five units from the station to the section. It is typical of all the charts, which have been constructed for integral distances from 1 to 20.

The mathematical study of the flow of electricity in a stratified medium has been continued. The two-layer, or single-overburden, problem was solved about ten years ago [4]. In this study, the classical method of images was applied and the resulting series were separated into two parts, one a divergent part independent of the distance from source to field-point, the other convergent and dependent on that distance. By means of an Eulerian formula, the convergent portions were summed and the results were tabulated for various combinations of the parameters. The construction and application of the table were discussed. Later, the tables were reduced to reference-curves which permitted direct superposition of the theoretical and observed curves [5]. By this superposition it is often possible to determine the depth of a contact and the resistivities of the beds. Figure 6 shows the theoretical curves for a bed of resistivity higher than that of the overburden. Figure 7 shows the curves for the reverse combination. Figure 8 shows a set of observations with four sections of the theoretical curves superposed. Only one of the four fits can be considered as satisfactory. Figure 9 shows a set of data for which the best agreement occurs midway between two curves of the reference-set.

The three-layer, or double-overburden, problem has been solved theoretically [6], but the results have not been reduced to a form sufficiently simple for practical purposes. While calculations are possible in isolated cases, it has seemed preferable to postpone numerical work until the formulas can be simplified. Considerable progress has been made along this line. The solution of this problem may be expected to lead to information in more complicated cases.

## References

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[2] Frederick W. Lee, A new depth meter for ice and snow, Internat. Ass. Hydrol., Bull. 23, pp. 761-771, Riga, 1938.
[3] See this volume, p. 390.
[4] Irwin Roman, How to compute tables for determining electrical resistivity of underlying beds and their application to geophysical problems, U.S. Bur. Mines, Tech. Pap. 502, Washington, 1931.
[5] Irwin Roman, Some interpretations of earth-resistivity data, Amer. Inst. Mining Metall. Eng., volume on Geophysical Prospecting, 1934, pp. 183-197.
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## AMERICAN GEOPHYSICAL UNION

### Twentieth Annual Meeting

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## SECTION OF GEODESY

Washington, D. C.
April 27, 1939

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## REPORT OF COMMITTEE ON RELATION OF INCH AND METER

R. M. Wilson

Those of you who attended the annual meeting of this Section on April 27, 1938, heard a paper entitled "A method for introducing a new standard of length" that was presented by Professor Philip Kissam, calling attention to the Bill then in Congress proposing to redefine the length of the inch. The paper has been published in the "Transactions of the American Geophysical Union" [19th Annual Meeting, 1938, pp. 94-96]. Its closing paragraph is as follows:

> "As the American Geophysical Union has as one of its functions the duty of offering advice to the Congress on technical matters, I move, Mr. Chairman, that the Chairman be empowered to appoint a committee to study the matter and to report what recommendations should be made to Congress by the Union."

This motion was adopted by the Section of Geodesy, and Chairman Garner appointed a committee of three to study the definition of the inch contained in the Bill designated H.R. 8974. The members of this special committee, namely, L. V. Judson of the National Bureau of Standards, H. C. Mitchell of the Coast and Geodetic Survey, and R. M. Wilson of the Geological Survey (Chairman), were appointed by a letter dated May 3, 1938.

It was immediately agreed that a questionnaire should be mailed in order to obtain material upon which a logical report might be based. A brief discussion of the question was prepared to accompany the questionnaire, and great care was taken to present the subject in a way to avoid any influence of opinion in the replies. No doubt most of you here received the discussion and the questionnaire. They were sent to all 194 members of the Section of Geodesy and to 59 other members of the American Geophysical Union who are not members of this Section. The mailing list included 129 members of university and college faculties representing educational institutions in all parts of the United States, and 56 were sent to representatives of State Planning Boards throughout the country. Also on the list were the names of 21 teachers of surveying who attended the meeting of the Society for the Promotion of Engineering Education at Louisville, Kentucky, on September 5, 1938, to include those not listed in any of the other groups just mentioned; a number of names from various sources were added by the individual members of the Committee. The total number of individuals on the mailing list was 472. Copies of the discussion were sent to six scientific and engineering organizations and to 11 engineering and scientific journals.

The questionnaires were mailed during the last week in September, 1938, and 131 replies received up to December 9, 1938, were considered in preparing the reports.

A majority and a minority report were prepared, and were submitted to the President of the Section of Geodesy on January 12, 1939. Each of the reports is accompanied by several pages of supplementary information, and there are three exhibits to which references are made. Exhibit B contains the replies to the questionnaire. I shall read only the bare reports themselves, which are not long.

### Majority report

> "Your Committee appointed to study H.R. 8974 and amendments to Section 2 thereof in so far as they may affect the interests of members of the American Geophysical Union submits the following report:
>
> "In Section 2 of H.R. 8974 the National Bureau of Standards proposes to standardize the inch in terms of the international meter by an equivalence which differs from that given in the Act of Congress of July 28, 1866, and for many years recognized as an exact and legal value. A section, No. 11, has been proposed by the Coast and Geodetic Survey which would exempt from the application of Section 2 certain survey- and map-work executed by Federal and State organizations. A modification [Exhibit A: "A method for introducing a new standard of length" by Professor Philip Kissam; read at the annual meeting of the American Geophysical Union, April 27, 1938] to the Bill has been proposed by Professor Philip Kissam of Princeton to permit the adoption of the 2.54 relation and at the same time protect the interests of those who have been using the 39.37 relation during the past 45 years or more.
>
> "Your Committee sought the help of the membership of the Geodetic Section of the American Geophysical Union and of scientists and engineers in various parts of the country by means of a questionnaire asking for comments on Section 2 of the Bill and on the proposed amendments. This was not intended as a vote or poll on the subject but rather as a search for any pertinent facts which might be helpful in preparing our report.

"In analyzing the returns from the questionnaire, as well as in evaluating other pertinent data, the Committee has been unable to continue in complete agreement, and the following paragraphs accordingly constitute a majority report, from which Dr. Lewis V. Judson of the National Bureau of Standards dissents, and which it is assumed he will replace with a minority report.

"From a study of the returns of the questionnaire [Exhibit B: "Replies received to questionnaire on the inch"] and from other authoritative sources [Exhibit C: Part 1, "Copy of resolutions adopted at Teachers Conference on Surveying," Rensselaer Polytechnic Institute, Troy, N.Y., March 26, 1938; Exhibit C: Part 2, "Reply to questionnaire by the Second Regional Surveying Conference], it appears that any change in the present legal equivalence of the meter and inch (1 meter = 39.37 inches exactly) is not desired by engineers and scientists engaged in or actively interested in geodetic work and would actually be detrimental to their interests. It further appears that to establish a new unit of length almost identical in value with the common inch now in legal use, and at the same time allow the common inch to retain any official status, would in effect establish two different standards for the same unit, and this would create an intolerable confusion.

"On the other hand, it is known that the establishment of an inch equal to 2.54 cm exactly is desired by an important and well-defined class of manufacturers engaged in international commerce with countries where the metric system is in common use. Its establishment is also desired by officials of the National Bureau of Standards having custody of the national standards of length. But, in so far as we can learn, the only need of the manufacturers which can not be fully satisfied by existing standards relates to geared machines which involve the use of both the common and metric standards. In such machines the equivalence of 1 inch = 2.54 cm exactly is considered necessary, not as a unit of length, but as a ratio which makes possible a simple gear-ratio not to be had with the existing length of 1 meter = 39.37 inches exactly. But it is as a ratio, and not as a length, that the proposed new equivalence is necessary.

"The special interest which the custodians of the national standards have in the proposed new equivalence is that it simplifies the division of a meter bar into very small graduations, and thereby promotes the comparison of common with metric standards. This is a purely mechanical advantage, the lack of which has not, in our opinion, in any way affected the high precision of the intercomparisons of those standards made during the many years the present legal equivalence of meter and inch has been in standard use. It is definitely of no advantage, in so far as we know, in the most precise standardizations (as of gage-blocks), in which wave-lengths of light and optical methods are used.

"Two of the three members composing your Committee therefore recommend that the American Geophysical Union express itself as opposed to any change whatsoever in the present equivalence of meter and inch, namely, 1 meter = 39.37 inches exactly, and that proper steps be taken to advise Congress of this opposition, and to express the hope that Congress at an early date will reaffirm this equivalence as a unit of length in a legislative Act.

"It is further recommended that the American Geophysical Union advise Congress that it is opposed to the equivalence, 1 inch = 2.54 cm exactly, contained in Section 2 of H.R. 8974 being given legislative approval as a unit of length, but that if it be found desirable to give that equivalence legal status, it be approved as a mathematical factor for use by those manufacturing and trade interests which have already adopted it for international purposes."

[Signed] R. M. Wilson (Chairman), Hugh C. Mitchell

## Minority report

"The undersigned concludes from his analysis of the replies to the questionnaire that it has not been indicated that any significant effect other than beneficial will result to those engaged in geophysical work from the adoption of the proposed law with Section 11 included as an amendment. Some have considered the proposed law as undesirable either because they do not want any change from existing conditions or because they want compulsory adoption of the metric system. Except for difference in certain computed results beyond the limit of practically all geophysical measurements, the proposed law does not appear to affect the measurements in this field.

"I am convinced that there is need for weights-and-measures legislation at this time. Since there are decided advantages in the use of the definition of the inch as equal to 0.0254 meter, and since any possible adverse effects in the field of geophysics are believed to be eliminated by Section 11 being added as an amendment as officially recommended by the U. S. Coast and Geodetic Survey, and since the proposed suggestion of Professor Kissam for a change in the proposed law is opposed as not being practical, necessary, or desirable, I recommend that no modification of Section 2 of the proposed law be made to change the proposed definition of the inch from 0.0254 meter, and that the amendment known as Section 11 be added to the proposed law to give the necessary exemption to computations involved in national and State surveying as officially requested by the U. S. Coast and Geodetic Survey.

"If it is considered advisable for the American Geophysical Union to make any recommendation to Congress, I propose and request that the recommendation of this minority report be transmitted to Congress.

"A supplementary statement is appended in which I give some reasons for statements made in my minority report and show why I dissent from the majority report."

[Signed] Lewis V. Judson

On January 14, 1939, the President of the Section of Geodesy offered the reports to the Executive Committee of the American Geophysical Union for appropriate action. The Executive Committee decided that the question was of interest primarily to the Section of Geodesy, and the Section was accordingly authorized to take its recommendations directly to the Congressional Committee on Coinage, Weights, and Measures. The American Geophysical Union as a whole, therefore, is not directly involved, and the reports represent the recommendations of the Section of Geodesy alone.

Meanwhile the 75th Congress adjourned, and I believe the action proposed in H.R. 8974 has not been submitted to the new Congress, which precludes further action for the time being.

The following letters show the present status of the reports:

Letter of February 16, 1939, by C. H. Swick, President, Section of Geodesy, to Honorable Andrew L. Somers, U. S. House of Representatives--"During the Third Session of the 75th Congress a Bill was introduced (H.R. 8974) 'To define certain units and to fix the standards of weights and measures of the United States.'

"At the annual meeting of the American Geophysical Union in April, 1938, a committee of the Section of Geodesy was appointed to ascertain the opinions of leading geodesists and surveyors over the country concerning Section 2 of the Bill which deals with the relationship of the meter and inch. This committee has made a report which, on the authority of the Executive Committee of the American Geophysical Union, I should like to present to your Committee on Coinage, Weights, and Measures if the Bill is again introduced and there are hearings on it.

"I shall appreciate your permission to present the report in brief form. If I appear before the Committee I hope, if that is agreeable to you, to be accompanied by Commander C. L. Garner, Chief of the Division of Geodesy of the U. S. Coast and Geodetic Survey."

Letter of March 2, 1939, by Honorable Andrew L. Somers, Chairman of Committee on Coinage, Weights, and Measures, to C. H. Swick--"Thank you for kindly offering to submit the report of the Executive Committee of the American Geophysical Union in connection with Section 2 of H.R. 8974, which was introduced by me and considered by this Committee, in the Third Session of the 75th Congress.

"Should the Committee have occasion to consider this Bill or one similar to it, at this session, I shall be more than pleased to afford you and Commander Garner an opportunity to be heard."

This completes the report of the present status of this matter.

(Note: The exhibits referred to above are on file with the original reports which are held by the Secretary of the Section of Geodesy.)

U. S. Geological Survey,
Washington, D. C.

## PROCEDURE AT MEETINGS OF THE INTERNATIONAL ASSOCIATION OF GEODESY AND OF THE INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Walter D. Lambert

(Abstract)

The International Union of Geodesy and Geophysics and its seven constituent associations all function under methods of procedure peculiar to themselves.

The International Union usually holds three general sessions and, until the Edinburgh Assembly of 1936, had no scientific commissions of the Union as a whole; at Edinburgh a Commission on

Continental and Oceanic Structure of the Union was established. This may pave the way for further scientific commissions of the Union as a whole. Apart from this, the Union commonly ratifies pro forma the scientific resolutions submitted by its several associations.

The officers to be elected at Washington are a President for three years to succeed Dr. la Cour and a General Secretary for six years to succeed Brigadier Winterbotham.

Much of the administrative work of the Union is prepared for presentation by the Committee on Administration and Finance, in which each country has one vote.

Each association has its own way of doing business. Many of them are like ordinary scientific congresses, in which papers are read and discussed and in which work of committees is reduced to a minimum. Resolutions may, of course, be adopted, some of which are recommended to the Union, as a higher body, for adoption.

In the Association of Geodesy, on the other hand, work of committees is the very life of the organization. Any one is free to attend meetings, though only members vote. Discussions in committee are often long and animated.

This country has not exerted the influence in the Association that would normally belong to it because of the failure to send enough delegates to be present at sessions of all committees.

For many of the subjects for which committees are formed there are also special reporters; the reports may form the basis of the committee's work. These special reports are published separately as part of the "Proceedings." There are also national reports setting forth the geodetic work of each country during the three years since the preceding Assembly. These reports are furnished to the Secretary's office in uniform format; there they are bound into volumes, provided with a table of contents, and distributed.

A hold-over from the pre-war International Geodetic Association is the Permanent Commission. This body perhaps suggested the formation of the Committee on Administration and Finance of the Union. This body is composed of the officers and members of the Executive Committee, each of whom must be from a different country, and of one member from each country not so represented. The Permanent Commission serves as an intermediate body between the Executive Committee and the Association of Geodesy. The individual members of the Permanent Commission serve as liaison agents between the President and Secretary on the one hand and the individual countries on the other, being more effective for this purpose than impersonal national committees.

The officers to be elected at this meeting are: A President for a six-year term to succeed Dr. F. A. Vening Meinesz, not reeligible; a second Vice-President for a three-year term to succeed W. D. Lambert (the new Vice-President must come from the country where the next meeting will be held); two members of the Executive Committee for six-year terms to succeed Brigadier MacLeod and Professor Weigel. The resolutions recommended by the various committees will also come up for adoption and will probably be adopted as a matter of course. Some of them will, in the usual course, be sent up by the Association to the Union with a recommendation for adoption by the higher body.

Various matters not strictly covered by the title were briefly touched on.

U. S. Coast and Geodetic Survey,
Washington, D. C.

## PRECISE ASTRONOMY ON THE SASKATCHEWAN-ALBERTA MERIDIAN BOUNDARY

Noel J. Ogilvie

The demarcation of the northerly part of the Inter-provincial Boundary between Saskatchewan and Alberta was carried out in 1938 by the Saskatchewan-Alberta Boundary Commission. In connection with this work, a precise astronomical determination of position was made at the north end of the Boundary by the Geodetic Service of Canada. A number of years previous to 1938, several determinations of latitude and longitude were made at other points on the line by officials of the Dominion Observatory. An analysis of these determinations will serve to give approximate values of the deviations of the vertical at the points of observation.

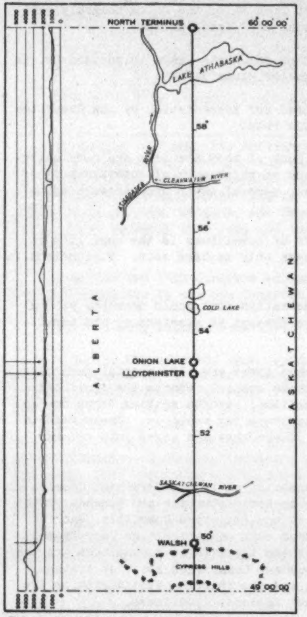


FIG. 1—DIAGRAM OF SASKATCHEWAN-ALBERTA MERIDIAN BOUNDARY SHOWING BOTH PLAN AND PROFILE

The meridian boundary (see Fig. 1) between Saskatchewan and Alberta extends from the International Boundary at latitude 49° northward a distance of almost 761 miles to the 60th parallel of latitude, defined by law as the northern limit of the two provinces in question. Prior to 1938, about 690 miles of the line had been opened and marked on the ground. The line was originally started in 1878 at latitude 52° 29' with a supposed longitude of 110° 00' 00". The accepted longitude for the point of commencement was not determined by a local astronomical observation. Instead, its value had been computed geodetically from township-corner to township-corner westerly along certain base-lines from the Principal Meridian (longitude 97° 27' 28".4) of the Land Survey System of Western Canada.

After the line had been projected a considerable distance both southward and northward, a telegraphic determination of longitude was made in 1888 at latitude 53° 43' by the late Dr. O. J. Klotz giving a value of 110° 00' 15".61. In 1909 and 1910, F. A. McDiarmid, then an official of the Dominion Observatory, observed for position on this meridian at latitude 49° 57' and 53° 17'; the resulting values of the longitude were 110° 00' 16".43 and 110° 00' 15".43, respectively. Subsequently, the southern terminus of the Boundary was tied in with the geodetic triangulation-net adjacent to the 49th parallel. Although the tie was not as precise as might be desired, the resulting value of the geodetic longitude of the southerly end of the line is reasonably accurate and gives a value of 110° 00' 15".15 computed on the 1927 North American datum.

From these determinations, it is apparent that the line was commenced at a point approximately 16" (1000 feet) west of 110° 00' 00", the supposed position in longitude. The projection of the line both northward and southward, under the direction of the Surveyor General of Dominion Lands, was carried on with great care.

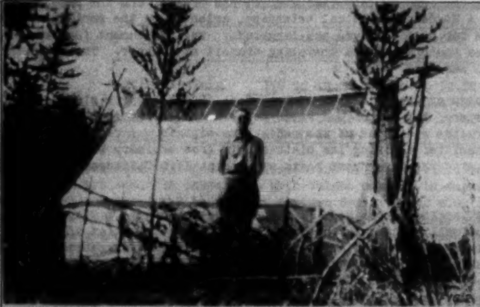
In spite of this, one serious error in the prolongation of the line occurred at Township 42 (latitude 52° 36') resulting in the projection of the line for several miles on an incorrect azimuth. As a result of this error, the whole northerly part of the meridian was displaced 137.9 feet to the westward relatively to the southerly part. This accounts for a change of 2".24 in geodetic longitude of the line at latitude 52° 36'.

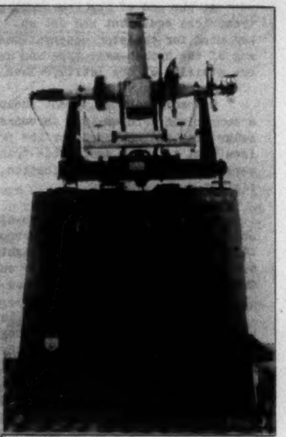
In general, observations for azimuth were made every few nights during the extension of the line. Azimuths accurate to about five seconds of arc were usually secured. When the line was found to have five seconds or more of deviation from the true north, it was deflected to bring it back to the meridian. With the exception of the gross error mentioned above, the average error in azimuth over the entire length of the line should not exceed three seconds of arc.

The lineal measurements of the line were, in general, made with two tapes, one graduated in chains and links and the other in feet. While definite figures on the accuracy attained are not available, it is reasonable to conclude that an average accuracy of 1/5000 was attained over the entire distance.

To find the approximate deviations of the vertical, geodetic values of the latitudes and longitudes of the astronomical stations established on the line have been computed using the southerly terminus as a point of origin. As the theoretical azimuth of 360° and the chainages along the line were used for these computations, it will be appreciated that the resulting deviations of the vertical are approximate values only. Geodetic positions based on triangulation-nets are not available for any points on the line except the southern point of origin.

The astronomical stations observed are as follows:





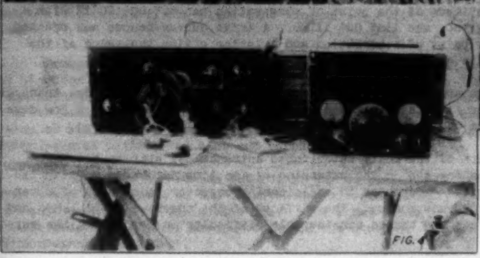


*FIG. 2—PORTABLE TENT-OBSERVATORY AT NORTH TERMINUS, SASKATCHEWAN-ALBERTA BOUNDARY*

*FIG. 3—HEYDE ASTRONOMICAL TELESCOPE SET UP IN TENT-OBSERVATORY*

*FIG. 4—PORTABLE RADIO TRANSMITTER AND RECEIVER*

| Year | Station | Latitude | Observer |
|---|---|---|---|
| | | ° ' | |
| 1888 | Onion Lake | 53 43 | O. J. Klotz |
| 1909 | Lloydminster | 53 17 | F. A. McDiarmid |
| 1910 | Walsh | 49 57 | F. A. McDiarmid |
| 1938 | North Terminal | 60 00 | C. H. Ney |

The determination made in 1888 at Onion Lake by Dr. Klotz was a telegraphic determination with Winnipeg as the base-station. The eye-and-ear method of observing star-passages was employed. Determinations were made on six nights giving remarkably consistent results. The exchanges of telegraphic time-signals between Winnipeg and Onion Lake were made by recording on moving tapes the incoming signals relative to the beats of the local sidereal chronometer.

The determinations made in 1909 and 1910 by F. A. McDiarmid were telegraphic longitudes with Winnipeg as the base-station. Star-passages and time-signals were recorded on an electric chronograph. Results equal in accuracy to modern radio longitudes were secured, independent determinations being made on five different nights.

The 1938 observations for position by C. H. Ney at the north end of the Boundary (latitude 60°) were made chiefly to determine the exact location of the 60th parallel of latitude. The longitude was observed as a check on the values determined farther south on the same line and also as a matter of scientific interest.

To reach the approximate location of the theoretical boundary-terminal, the astronomical field-party under Mr. Ney proceeded by boat down the Athabasca and Slave rivers to Fitzgerald. The remainder of the journey, a distance of 60 miles, was made by aeroplane. Landing on a small lake near the assumed position of the boundary-terminus, an approximate determination of position was made. The ensuing calculations showed that the desired location was about a half mile to the southwest. To determine this point, a survey-line was cut through the thick timber on a calculated azimuth and the distance measured with a steel tape.

At the end of the traverse, a tent-observatory (see Fig. 2) was erected and the precise astronomical equipment was set up. A Heyde astronomical telescope, oriented in the meridian plane, was used for the star-observations for both latitude and longitude. The instrument (see Fig. 3) was of the broken-axis type and was equipped with a traveling transit-micrometer. The value of one division of the latitude-level was 1".18.

The accessory equipment included an electric pricker-type tape-chronograph, a sidereal and a comparison vernier-type chronometer. The latter was rated to gain one second in 50 on mean solar time and was used for the precise reception of the radio time-signals. A radio receiver (see Fig. 4) and a small code-transmitter deriving its plate-supply from ordinary B-batteries were used for daily communication with the Government radio station at Fort Chipewyan, 100 miles distant.

Independent determinations of longitude were made on three different nights giving a result accurate to about ten feet astronomically on the Earth's surface. The determination of the latitude was much more precise. Eighty-one pairs of stars were observed by Talcott's method over six different nights. One pair only was rejected during the computation, which was carried on from day to day during the period of observation.

The resulting value of the latitude of the point of observation was 60° 00' 00".23 with a probable error of 0".058. The longitude was 110° 00' 11".30. A large survey-beacon was erected over the concrete pier marking the point of observation and a letter giving the value of the latitude was left in a sealed bottle on top of the pier.

In response to a radio message announcing the completion of the operation, a large transport-plane arrived the following day and flew the party and equipment to Fort Chipewyan. A few days later, the return journey to Ottawa was commenced.

Meanwhile 30 miles to the south of the newly established astronomical station the line-cutting party under B. W. Waugh was engaged in the extension of the line northward. The neighboring territory, entirely uninhabited except for an occasional prospector, consisted of alternate stretches of rocky ridges and spruce muskeg. The surfaces of the numerous small lakes and streams almost equaled the land-areas and caused considerable difficulty in projecting the meridian northward.

On September 1, the line-cutters topped the last ridge, worked across a one-mile stretch of muskeg, and stopped the cutting. They had arrived at latitude 60°, the northern limit of Saskatchewan and Alberta as indicated by the astronomical pier of the Geodetic Service of Canada.

Being unable to predict the astronomical value of the longitude at the northern end of the meridian, no special effort was made by Mr. Ney to establish the astronomical pier at any particular value of longitude. The actual value of the pier (110° 00' 11".30) was the result of an attempt to choose a point considerably west of 110° 00' 00", yet not quite equal to 110° 00' 16", the average value of the longitude of the Boundary several hundred miles to the south.

The meridian hit 188 feet to the west of the geodetic pier. This lineal offset is the equivalent of 3".70 in longitude. When added to the value for the pier, it gives an astronomical value of 110° 00' 15".00 for the longitude of the northern terminus of the line.

Tables 1 and 2 give the astronomic and the approximate geodetic values of the latitudes and longitudes of the four precise astronomical stations established on the Boundary-line. As pointed out before, the geodetic values computed from the theoretical azimuth and the line-chainages are subject to unknown errors. However, even at the extreme northerly end of the line, the discrepancies in geodetic values should not exceed two seconds of arc.

Table 1--Deviations of the vertical in meridian plane

| Station | Astronomical latitude | Geodetic latitude | Astronomic minus geodetic |
|---|---|---|---|
| | ° ' " | ° ' " | " |
| North Terminus | 60 00 00.00 | 59 59 59.90 | +0.10 |
| Onion Lake | 53 42 54.53 | 53 42 53.75 | +0.78 |
| Lloydminster | 53 16 44.28 | 53 16 40.13 | +4.15 |
| Walsh | 49 57 43.95 | 49 57 37.03 | +6.92 |

Table 2--Deviations of the vertical in the prime vertical

| Station | Astronomical longitude | Geodetic longitude | Astronomic minus geodetic |
|---|---|---|---|
| | ° ' " | ° ' " | " |
| North Terminus | 110 00 15.00 | 110 00 17.39 | -2.39 |
| Onion Lake | 110 00 15.61 | 110 00 17.39 | -1.78 |
| Lloydminster | 110 00 16.43 | 110 00 17.39 | -0.96 |
| Walsh | 110 00 15.43 | 110 00 15.15 | +0.28 |

The tabulated values of the deviations of the vertical in both the prime vertical and meridian planes are small in comparison with values derived in eastern Canada, where about 145 accurate determinations have been made. The maximum deviation of 6".92 in the meridian plane at "Walsh" on the Saskatchewan-Alberta meridian boundary is approximately one-third of 20".27, the deflection in the meridian plane at Rivière la Madeleine on the south shore of the St. Lawrence River in the Province of Quebec.

The effect of topography on the plumb-line would naturally be small on the Saskatchewan-Alberta Boundary. Walsh astronomical station in latitude 49° 57' giving a deviation of 6".92 indicates a deflection of the plumb-line towards the south of this point. The reason is quite apparent.

Topographic maps of the area show the Cypress Hills with a maximum elevation of 4546 feet at 25 miles to the south of Walsh. Northward, the Boundary-line extends over the prairie tableland for several hundred miles before passing into the northern bush-area which extends a considerable distance north of latitude 60°. This entire area is characterized by the absence of mountains or hills of any great magnitude. In general, the area approximates to a slightly tilted plane sloping towards the east and north.

Perhaps some day in the future, it may be possible to extend a net of primary triangulation over the area adjacent to the Saskatchewan-Alberta Boundary. It might even be possible to continue it northward to the Arctic Sea. Such a net would be of great benefit in the investigation of the size and shape of the Earth and in the study of isostasy for the northern part of the North American Continent.

Geodetic Service of Canada,
Department of Mines and Resources,
Ottawa, Canada

## KEY FOR THE RECOGNITION OF PHYSIOGRAPHIC PROVINCES FROM TOPOGRAPHIC MAPS

Lawrence Whitcomb

For several years it has been felt that there were great advantages to be found in the use in teaching of the special blue and brown prints of topographic maps issued by the United States Geological Survey. These maps, which give the contours and water but which do not show any of the culture, are available for many of the quadrangles. Among the advantages of these maps is the fact that topographic forms, which are often masked or rendered inconspicuous by the culture, are more clearly seen in their true relationship to the surrounding country. An example of this may be observed on the Coatesville Quadrangle, Pennsylvania-Delaware. On the regular map the city of Coatesville and the four-track road-bed of the Pennsylvania Railroad partially obscure the topography of the Chester Valley, but on the map of the same quadrangle without the culture the long narrow valley is readily seen and is the most conspicuous topographic feature. If maps are to be used as a means of picturing topography, the clearer the map the more satisfactory it becomes.

Another asset to be found in the maps without the culture is the lack of geographic names. A student naturally will use all the information that is available in solving a problem. A map with many swamps and depressions containing water can not logically be ascribed to the work of glaciers if it is labeled Florida, while if it is known to be in Minnesota, from the viewpoint of the student, the glacial origin is practically proven.

Probably the greatest value of these special maps is to be found in the study of physiographic provinces for here a student must observe and correctly interpret the topography. Upon the basis of his results he determines what province is represented, receiving no aid from the culture. Studies of this type lead to critical examination of the topography and bring about a clearer understanding of the basis for physiographic subdivision.

After attempting for some time to develop work along this line at Lehigh University, it was found that the average student did not have a definite knowledge of what points were significant nor a well-developed plan of procedure. In order to aid the student and to establish a definite mode of attack, a preliminary key was developed. This key was discussed at the meeting of the Pennsylvania Academy of Science in 1937 and is published in the Proceedings of that society [L. Whitcomb, Proc. Pa. Acad. Sci., v. 11, pp. 61-64, 1937]. After continued use by undergraduate and graduate students it is deemed advisable to revise this key to remove some of the more flagrant sources of trouble. It must, of course, be realized that any such teaching aid has to be brief if it is to be usable and that it cannot be 100 per cent perfect and still be short enough to justify its existence. It also is impossible to have such a key fit every topographic map published, as many areas are of such indefinite character that they might fulfill the requirements of more than one subdivision.

It has been found that when the key is used at first with a carefully selected group of maps which are typical of the various physiographic subdivisions of the country it develops confidence and a sound method of procedure. Once the student discovers that there are fundamental principles that can be relied upon to give the correct analysis of simple maps, he is then ready for the more complex or less characteristic ones. It is advisable that the first maps used be so selected that each quadrangle falls entirely within a single physiographic province. After a half dozen have been studied, it is possible to include some that contain portions of two distinct provinces without unduly confusing the student. The problem of recognizing the less obvious differences between two divisions of the same province is the third stage in the program.

After several years of experiment it has been found that undergraduates with one semester (10 three-hour exercises in the laboratory) of map-interpretation can handle this type of work successfully. By the end of the second exercise in the laboratory of this type the key is no longer consulted for every new quadrangle for by then most men have gained sufficient confidence in their ability to handle ordinary maps and refer to it only for the unusual or less typical examples.

The key is divided into four parts, the first dealing with basic information that is needed in studying every map, the second giving the methods of determination of the physiographic province, the third containing certain generalized information, and the fourth indicating the type of clues that may be used in subdividing the provinces into sections.

The key in its revised form is as follows:

### Key to determination of physiographic provinces of topographic maps which lack culture

(I) Basic information
  (A) What is the scale?
  (B) What is the contour interval?
  (C) Is the map uniform or varied?
    (1) If uniform, probably one province
    (2) Marked variation in topography probably indicates two or more physiographic provinces; solve for each portion separately, then find place where results obtained will fit together
    (3) Less pronounced variation probably indicates two or more sections within a single province; solve first for the province, then for the section
(II) Method for determination of physiographic province: Is it plains, plateaus, or mountains?
  (A) Plains
    (1) Elevation
      (a) Under 500 feet, probably coastal plain
      (b) 500 to 2000 feet, probably central lowlands
      (c) 2000 to 6000 feet, probably great plains
      (d) 6000 to 8000 feet, probably Wyoming Basin
    (2) Glaciated or non-glaciated?
      (a) If glaciated it is north of the Ohio and Missouri rivers
        (x) If direction of glaciation is from west of north to east of south it is probably east of the State of Ohio
        (y) If direction of glaciation is from east of north to west of south it is probably west of New York State

- (b) If map does not show effect of glaciation it may be north of Ohio and Missouri rivers, but probably not
- (3) Direction of flow of major rivers
    - (a) Streams flow east into the Atlantic Ocean, the Mississippi River, or the Gulf of Mexico
    - (b) Streams flow south into the Gulf of Mexico or Long Island Sound
    - (c) Streams flow west into the Mississippi River or the Pacific Ocean
    - (d) Streams flow north into the Great Lakes
- (4) Is it an arid region? If so, it is probably west of the Mississippi River
- (5) Does a large body of water show on the map? If so, see special section on shore-lines

(B) Plateaus

- (1) Elevation
    - (a) 500 to 1000 feet may be Piedmont Plateau or interior low plateaus
    - (b) 1000 to 1500 feet may be Driftless Area of Central Lowlands (see section IV,D,1)
    - (c) 1000 to 3000 feet may be Appalachian plateaus or Ozark plateaus
    - (d) 3000 to 5000 feet probably Columbia Plateau
    - (e) 5000 to 7000 feet probably Colorado Plateaus
- (2) Glaciated or non-glaciated (see above under Plains)
- (3) Direction of flow of major rivers (see above under Plains)
- (4) Are there entrenched meanders? If so, it may be
    - (a) Appalachian plateaus
    - (b) Interior low plateaus
    - (c) Ozark plateaus
- (5) How great is the relief of major stream-valleys?
    - (a) Over 1000 feet, probably Columbia or Colorado plateaus
- (6) Is it an arid region?
    - (a) Very arid, Colorado plateaus
    - (b) Intermediate, Columbia plateaus
    - (c) Moist, east of Great Plains
    - (d) Playa lakes, probably Basin and Range Province

(C) Mountains

- (1) Elevation
    - (a) Over 7000 feet must be west of Mississippi River
    - (b) Under 7000 feet
        - (x) Mature mountains cut in rocks of uniform hardness, probably Blue Ridge, New England, or Adirondack Province
        - (y) Youthful mountains cut in rocks of uniform hardness, probably Pacific Border Province
- (2) Continental glaciation
    - (a) See above under Plains
    - (b) Mountains showing continental glaciation
        - (x) New England Province; direction of glaciation from north-south to northwest-southeast
        - (y) Adirondack Province; direction of glaciation from east of north to west of south, more swamps than in New England Province
- (3) Mountain glaciation
    - (a) Glaciers present; probably northern Rockies or Cascades, if present on volcanic peaks it is the Cascades
    - (b) Glaciers absent; may be any of western ranges
- (4) Folded strata; trellis drainage on hard and soft beds
    - (a) Mountains running east of north to west of south, probably Valley and Ridge Province
    - (b) Mountains running east and west, probably Ouachita Province
- (5) Mountains with large alluvial fans at base in arid country, probably Basin and Range or Pacific Border Province; if Playa lakes are present, probably Basin and Range Province

(D) Shore-lines

- (1) Is water at sea-level, the ocean
- (2) Is water above sea-level, probably the Great Lakes
- (3) Is area glaciated with water at sea-level, probably New England Province or Long Island portion of Coastal Plain Province
- (4) Is area low-lying plain with water at sea-level, probably Coastal Plain
- (5) Do mountains approach the shore line? If so, probably Pacific Border Province
- (6) Direction of shore-line and relative position of land and water are often of great help

- (III) Additional aids and general statements
  - (A) If the scale is 1:250,000, it is probably west of the Mississippi River
  - (B) If the contour-interval is over 100 feet, it is probably west of the Mississippi River
  - (C) If bench-marks are arranged in pattern indicating township- and section-corners, it is probably west of Mississippi River
  - (D) Relative width of map; wide maps in southern and narrow maps in northern part of country due to the convergence of meridians
  - (E) Plateaus can be differentiated from plains by deeper entrenchment of major streams
  - (F) Effect of Mountain Glaciation on mountain ranges of Western United States is more pronounced to the north and less obvious to the south
- (IV) Method for determination of section within a Province
  - (A) New England Province
    - (1) Low glaciated rocky coast probably north of Cape Cod
    - (2) Low shore-line with glacial till probably Cape Cod or southern edge of province
  - (B) Coastal Plain Province
    - (1) Low east-west coast-line with terminal moraine, outwash plain and barrier beaches, Long Island
    - (2) Ria Coast probably the Embayed Section
    - (3) Low area with sink-holes, Floridian Section
  - (C) Valley and Ridge Province
    - (1) Major drainage, transverse, Middle Section
    - (2) Major drainage, longitudinal, Southern Section
    - (3) Canals present along major rivers, Middle Section
  - (D) Central Lowlands Province
    - (1) Driftless Area is plateau, dissected by dendritic streams to stage of adolescence and is out of harmony with rest of province
    - (2) Abundant lakes and swamps of glacial origin, Eastern or Western Lake District

As further means of subdividing these and other provinces soon becomes obvious to the individual as a result of studying numerous maps, it has not been considered wise to enlarge this portion of the key.

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## NEW METHODS OF REPRESENTING TERRAIN

H. L. Cooke

(Abstract)

The present paper is a preliminary report on work being carried out at Princeton. The methods of representation constitute an offshoot of work on the general problem of surveying with photographs from aeroplanes, with which the author has been engaged over a number of years.

The general method of air-survey, as at present practiced, consists in setting up pairs of overlapping photographs from aeroplanes in such a way that a stereoscopic image of the terrain, to known scale and orientation, is produced, and then securing measurements, etc., of this image. In ordinary practice this results in a topographical map of the usual type. The writer has been working on a variation of this procedure in which a three-dimensional carving, or relief-map, of the terrain is produced, having any desired relation of vertical and horizontal scales. The carving, or a replica of the carving, is then photographically sensitized, returned to position beneath the projectors casting the plastic image, and exposed, the result being a photographic relief-map free from parallactic distortion. (A model of this type was exhibited at the meeting.)

Later developments of this process, at present under investigation, involve the use of layered blocks for the carving, whereby the contours are produced directly by the carving, and a further extension of the method is adapted to produce flat photographic maps in which all photographic detail will appear in correct planimetry with contour-lines and topography shown in white lines on the photographic background. It is possible by this method to have the contours shown as shaded zones instead of lines, and thus to avoid all drawing of contours. Experiments indicate that this method will be rapid and accurate, and will result in maps of a new type on which will appear all known information about the terrain, both photographic and topographic, in correct relation. The usefulness of maps of this type is apparent.

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# THE GEOLOGICAL SIGNIFICANCE OF GRAVITY-INVESTIGATIONS IN VIRGINIA

George P. Woollard

Introduction--There are believed to be three fundamental controls of the gravity-anomalies observed in Virginia. These are the thickness and lateral extent of the low-density sediments, the local lithologic variations in the crystalline basement-rocks, and the thickness and configuration of the acidic upper crust which rests upon (and may project into) a denser substratum.

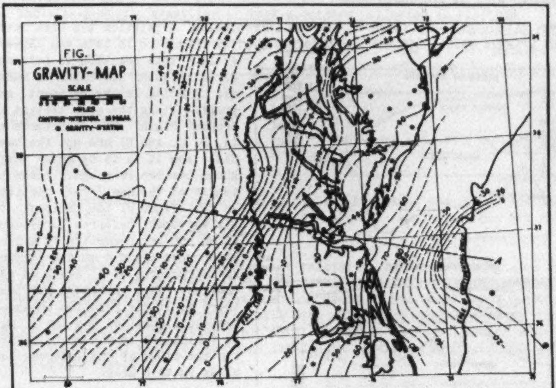
Since the geologic implications of the above are so marked, and the gravity-picture in other areas of the eastern seaboard is so similar to that observed in Virginia, the writer feels that all of the data used in the interpretations (seismic, geologic, and gravitational) should be presented for both inspection and criticism.

Historical review--Although the generalized gravity-picture in Virginia has not changed since the first gravity-maps were published in 1912 [Special Report No. 10, U. S. Coast and Geodetic Survey], the geologic significance of the anomalies is only just beginning to become apparent.

In 1936 [see No. 1 of "References" at end of paper] attention was called to the fact that a gravity-profile through the Virginia Region seemed to show some agreement in the Coastal Plain Area to the thickness of light sediments present, but the gravity-structure believed to reflect the Appalachian Trough did not agree in geographical position with the Appalachians. Instead, it occurred out in the Piedmont Area of crystalline rocks. In 1937, Swick [2] called attention to the lack of agreement between the configuration of the gravity-profile across the Coastal Plain and the thickness of sediments determined seismically by Ewing, Crary, and Rutherford [3]. He also pointed out that a correction for a mass of sediments of density 2.0, equal in thickness to that shown by well-data at the coast, 2250 feet, yielded only 19 milligals whereas the observed anomaly was minus 45 milligals. This past year the writer [4] called attention to the agreement noted between the trend of the anomaly-curves and the seismic velocities for the crystalline basement in that area where the effect of the sediments was small. Subsequent gravitational and seismic investigations in New Jersey have verified this relation, and it is now believed possible with this information and additional gravity-data to postulate the geologic significance of the gravity-anomalies in the Virginia area.

Virginia gravity-field--Figure 1 shows the variations of the gravitational field in Virginia. This is an isoanomaly contour-map based on the international formula with a depth of compensation of 113.7 km.

It will be noted that the gravity-structures consist essentially of a broad trough of about minus 50 milligals in the Blue Ridge Region separated from a much narrower trough of minus 80



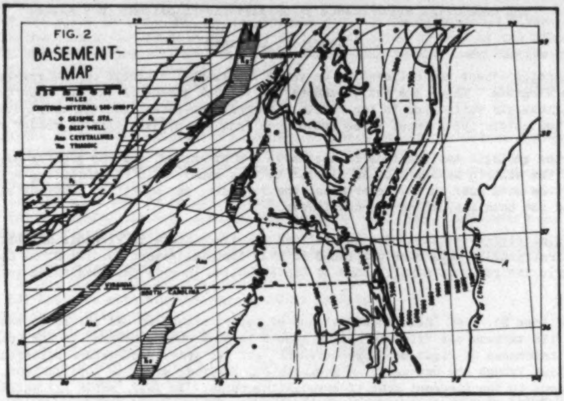


FIG. 2
BASEMENT-MAP

milligals in the offshore area by a gravitational ridge of plus 20 milligals which runs through Washington. On the flanks of these main gravitational structures occur minor ones of less intensity. All of the structures exhibit a parallelism in trend and this is conformable to the trend of the Appalachian Mountains. A highly significant feature of this agreement in trend is that regional gravitational studies made by the writer [5] show these structures to parallel the Appalachians throughout their length. Another feature is that the main gravity-structures do not vary more than plus or minus 10 milligals in intensity from the observed values in Virginia. The only marked variations are in the lateral extent of the respective structures which are everywhere continuous with the possible exception of two of the minor structures which are either extremely narrow or else pinch out in the neighborhood of Washington.

Basement-configuration--It is seen in Figure 2, which is based on logs of deep wells and seismic-depth determinations both in Virginia and southern New Jersey, that the general configuration of the crystalline basement-rocks beneath the Coastal Plain appears to agree with the gravity-field in this area, that is, that the deeper the basement lies buried beneath the light coastal-plain sediments, the more negative the anomaly. That this indicated agreement might be only an illusion will be discussed later.

Basement-lithology--As pointed out in the introduction, a relation has been noted between the basement seismic velocities and the observed gravity-anomalies in both New Jersey and Virginia. This relation is indicated in Figure 3, which shows the depth to Basement, seismic velocity in the Basement, and gravity-profile along the same section across the Coastal Plain. The structures traversed (A, B, C, and D) are not the same in each case, and it is to be noted that the Virginia Section is roughly three times the length of the New Jersey Section. As long as the effect of the sediments is small, the agreement referred to between the velocities and the anomalies is apparent; as on structures C and D on the Virginia Profile, and structures B, C, and D on the New Jersey Profile. This agreement and the fact that there is little relation between the basement-configuration and the anomalies point to variations in basement-lithology as being the cause of the observed local anomalies in this area.

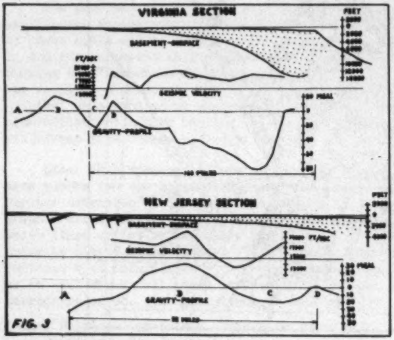
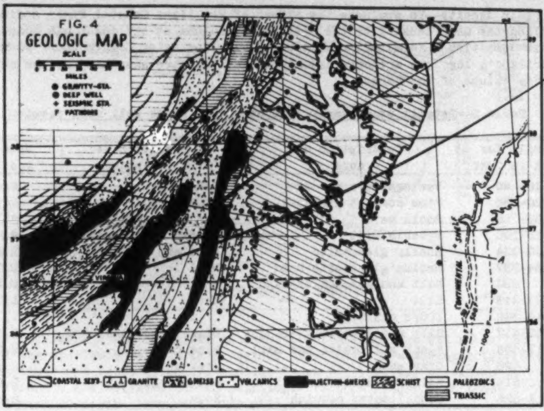


FIG. 3

FIG. 4
GEOLOGIC MAP



From a comparison of rock-types adjacent to gravity-stations in the exposed crystallines of the Piedmont it is possible to gain some idea as to which rocks are associated with the various anomalies. This information, together with that gained as to the nature of the basement-lithology from deep wells, permits gravitational, velocity, and lithologic correlations to be postulated which are believed to approximate the true conditions.

Through the aid of the Virginia Geological Survey and various well-drilling organizations in the Virginia Area, the writer was able to secure data as to the nature of the basement-lithology at various points beneath the Coastal Plain and also rock-samples of the basement-complex for conducting specific-gravity determinations.

The generalized geologic map of the Virginia Area (Fig. 4) shows the variations in lithology of the crystallines in the Piedmont and gives also an idea as to the changes that might be expected in the Basement in crossing the Coastal Plain. The significance of these changes in terms of specific gravity is shown in Table 1 giving values established from field-specimens collected in Virginia.

Table 1--Specific gravities of rock-specimens collected in Virginia

| Rock | Range specific gravity | No. of specimens | Average specific gravity |
|---|---|---|---|
| Gneiss | 2.44 to 2.96 | 6 | 2.67 |
| Granite | 2.60 to 2.69 | 4 | 2.63 |
| Basic injection gneiss and greenstone | 2.91 to 3.54 | 6 | 3.13 |
| Schist | 2.46 to 2.84 | 5 | 2.64 |
| Rhyolite | 2.58 to 2.58 | 2 | 2.58 |
| Triassic sediments | 2.47 to 2.60 | 3 | 2.55 |

Although it is impossible to evaluate exactly the weighted mean density of the basement-rocks, it would appear from the above values that 2.67 is a fair approximation, and this value was used in calculations to be discussed later.

That the gravity-anomalies in the Piedmont are related to the lithology is also shown by the values observed at stations No. 698 and No. 700. The former is at Amelia and located on the injection-gneiss adjacent to a hornblende-dyke one-quarter mile wide which has a density of 3.54, whereas the latter is near Petersburg on a granite with an average density of 2.63. The gravity-anomalies at these two localities are plus 21 milligals and minus 19 milligals, respectively, and it is to be noted that for the same lithologic relations similar anomalies are found elsewhere in the eastern seaboard.

Coastal Plain density--To evaluate the effect of the light Coastal Plain sediments upon the gravity-anomalies the mean density of the sedimentary column at the coast was computed from the lithologic unit-densities determined from cores of the Gloucester County Court-House Well. Table 2 shows the driller's log, the writer's description of the core-samples, and the determined specific-gravity values of the cores.

Table 2--Details of Gloucester County Court-House Well core-samples

| Sample for depth in feet | Description of core | Driller's description | Specific gravity |
|---|---|---|---|
| 10- 20 | Variegated clay | Red clay | 2.38 |
| 20- 35 | Fine compact glauconite | Blue marl | 2.27 |
| 35- 65 | Shell marl | Marl with shell | 2.17 |
| 65-100 | Friable silt | Sticky blue marl | 2.23 |
| 100-134 | Shelly glauconite | Marl and shells | 2.55 |
| 134-337 | Medium glauconite-sand | Marl | 2.11 |
| 290 | Silt and glauconite-sand | Marl | 2.20 |
| 337-349 | Silt | Marl | 1.76 |
| 349-382 | (Core missing) | .... | .... |
| 382-417 | Silt and glauconite-sand | Black gumbo and sand | 1.58 |
| 417-598 | Black glauconite and marl | Blue clay | 2.30 |
| 596 | Gray sand | Gray sand | 2.10 |
| 600-613 | Silt and shell-sand | White marl | 2.06 |
| 613-625 | Consolidated coquina | Rock | 2.62 |

| Rock | Average spread specific gravity | Average specific gravity |
|---|---|---|
| Sand | 2.06 -- 2.20 | 2.19 |
| Marl | 1.58 -- 2.27 | 2.05 |
| Shell marl | 2.17 -- 2.55 | 2.36 |
| Gumbo and clay | 2.30 -- 2.38 | 2.34 |
| Coquina | | 2.62 |

By using these average-density values for the corresponding lithologic units reported in the deep wells to Basement at Matthews, Moores Bridge, and Fortress Monroe, it was possible to determine the mean average density of the sedimentary column overlying the crystalline basement. These values are shown in Table 3.

Table 3--Average densities

| Well | Basement-depth | Average density (weighted) |
|---|---|---|
| Gloucester Court-House | To 613 feet | 2.195 |
| Matthews | 2300 feet | 2.206 |
| Fortress Monroe | 2240 feet | 2.220 |
| Moores Bridge | To 1720 feet | 2.230 |
| Average value for column to Basement | | 2.218 |

Density-distribution--What the actual density-distribution is in the basement-crystallines has to be surmised in part from the seismic and gravitational relations previously noted, but well-data show that a granite similar to the Petersburg Granite is present in the Matthews Area, volcanics similar to the Aporhyolites of the Piedmont lie in the Fortress Monroe Area, and that in the area near the Fall Line there are both fine-grained and porphyritic granites, and also a hard black rock which from the driller's description appears to be a hornblendite similar to that observed at Amelia. The velocity-density correlations used are based upon the above and serve to act as a guide in extending the basement-lithology into unknown areas. The tentative relations used are shown in Table 4.

Table 4--Tentative relations used of seismic velocity and density

| Rock | Seismic velocity in feet per sec | Density |
|---|---|---|
| Hornblendite | 21,000 | 3.54 |
| Injection-gneiss (basic) | 19,000 | 3.13 |
| Gneiss (acid) | 18,000 | 2.67 |
| Schist | 17,000 | 2.64 |
| Rhyolite | 17,000 | 2.58 |
| Granite | 13,000 to 15,000 | 2.63 |

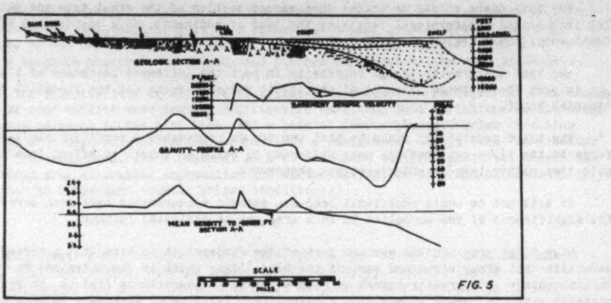


FIG. 5

The values of Table 4 are not given as absolute determinations but rather as tentative ones based upon all the available data in this region. That there are marked differences between some of these values and those noted for similar types of lithology elsewhere is acknowledged, but these differences are believed due to petrologic factors rather than those of error. Only considerable future research along this line will clarify this point.

Figure 5 shows the geologic section based upon the above relations in conjunction with the direct observational data. In order to see if there was an agreement between this postulated density-distribution and the gravity-anomalies, such as has been found in similar studies in the Bighorn Mountain-Black Hills Region of Montana, Wyoming, and South Dakota [6], the mean column-density down to a depth of 20,000 feet below sea-level was computed and plotted against the anomaly-curve.

The method was to compute the sedimentary column with its actual depth, but the crystalline basement-column as having its surface-lithology only extending down 5000 feet below the surface. Below this depth the average mean density for all the crystallines, 2.67, was used since it was impossible to know the configuration or extent of the crystallines with depth. That an approximation of the true conditions was determined in the central portion of the area is shown by the agreement of the density-curve with the anomaly-curve in this region. The lack of agreement at the two extremities of the profile is believed to reflect two different conditions.

Continental-Shelf Area--On the eastern end of the section it is seen that the anomaly-value indicated rises from a value of minus 80 milligals to a positive value, although the geologic section based upon seismic-depth determinations has its maximum thickness of low-density sediments at this point. The writer believes that these outer anomaly-values which were established by Dr. Vening Meinesz [7] would be considerably reduced if a correction were introduced for the actual density of the shelf-sediments. The situation is analogous to that noted for the border-stations near the crystalline massifs in the Beartooth and Bighorn Mountains of Montana and Wyoming where they come into contact with the depositional basins. Observations made in the basins have a large correction introduced in the topographic reduction for the low-density sediments present but only a small one in the compensation-reduction since this effect involves primarily the outer zones embracing the crystalline massifs of density 2.67. Similarly, observations made on the edge of the crystalline massifs have little change introduced in the topographic reductions, but have marked ones in the compensation-reductions since in this case it is the outer zones which embrace the area of marked departure from the normal value of density 2.67. In the present case for stations at the edge of the Continental Shelf, the shelf-sediments depart markedly from the assumed density of 2.67 while the mass of sea-water off the edge of the Shelf is corrected for. The result is that the topographic reduction should be subject to a marked correction which would serve to reduce the anomaly. This correction though, compared to the observed anomaly, is so small that it would serve only to widen the indicated negative structure and make it less sharp. The degree of the correction is indicated in the reduction for Station No. 90, Virginia Beach. Here carrying the correction to Zone 18, approximately 116 miles, reduces the anomaly from minus 50 milligals to minus 41 milligals. The method of correction is the same as that described in connection with similar corrections in the Bighorn Area of Montana and Wyoming [6].

In the light of the above it would appear that this marked gravity-trough represents one of two or possibly three conditions:

(1) That there exists an actual down-warped section of the crust into the substratum resulting from either compressional forces or the load of sediments, or a combination of these in the Continental-Shelf Region.

(2) That the gravity-trough represents in part the increased thickness of light sediments and in part the eastward thinning of the acidic basement-rocks (of the Piedmont) toward the Continental Shelf.

The third possibility would be that the trough represents a condition similar to that set forth in the first explanation, only differing by being an inherited effect from perhaps Paleozoic time rather than a contemporaneous phenomenon.

It will not be until additional deep-sea seismic measurements have been carried out that the significance of the anomalies in this area can be evaluated further.

Blue-Ridge Area--In the western part of the Piedmont it is seen that a marked gravity-trough underlies that area, along and east of the Blue Ridge, which is characterized by overthrust faults. Since this gravity-trough is such a marked and continuous feature, it has long been associated with the former Appalachian geosyncline. Its lack of agreement in geographical position, however, with the Appalachian Mountain System has caused considerable conjecture as to what its true geological significance is. Although present supplementary data does not permit this question to be answered conclusively, the writer would like to present three interpretations which he feels warrant attention:

(1) The present gravity-trough reflects a basin of low-density sediments covered by overthrust crystalline rocks. This basin might represent the eastern side of the former Appalachian geosyncline which was occupied by low-density, coarse, clastic material in contrast to the dense limestones deposited farther to the west as seen in the Great Valley, or a separate depositional trough similar to the situation observed in New England.

(2) The gravity-trough is due to the tectogene associated with a former Appalachian System of island-arcs which lay to the east of the foredeep in which the Paleozoic sediments accumulated, this latter feature being the observable Appalachian Region.

(3) The trough represents the effect of late Paleozoic compressional forces which fractured the crust and overthrust the eastern member so that it forced the overridden member down into the substratum.

In discussion of the various interpretations it is believed that, aside from the problem of accumulating the great thickness of light sediments required to yield the observed anomaly, they could not have persisted for such a long period without marked alteration to denser types of lithology. Further, if the anomaly were due to the warping of the crust under great depositional basins, then the anomaly should carry under the limestone area to the west for, although the limestones are heavier than the assumed normal density, they are much lighter than the substratum material that would be displaced by such downwarping. Also, if the anomaly were due to the deformation of the crust into the substratum, it is hard to visualize how the anomaly would persist without isostatic compensation being accomplished in the time-interval involved. This argument holds for all the presented interpretations, although presumably the original anomaly in the case of the island-arc hypothesis would be much greater than in the other two cases.

Arguments that might be advanced in favor of the various interpretations are that there is accumulating evidence that much of the supposed crystalline area of the Piedmont is really only altered Paleozoic sediments, and this alteration might be confined to the upper portion which was in direct contact with the overthrusts. That if the present depositional column is any gage as to thickness, then there should be somewhere much greater deposits of lower Paleozoic or earlier clastics than we know at present. In favor of the island-arc hypothesis, it may be pointed out that both the Appalachians and the gravity-structure have an arcuate pattern, and that those peculiarities associated with present island-arc structures, such as the zone of overthrusts between the foredeep and the axis of the gravity-trough, the belt of serpentines, and the line of volcanic activity back of the gravity-axis, are all present in their correct positions.

The third hypothesis assumes that isostatic compensation for Paleozoic phenomenon was accomplished and that the present anomaly represents the effect of subsequent crustal forces. Evidence for this is the geologic history of the region, showing, since the Appalachian orogeny, Triassic arching and faulting, Jurassic faulting and tilting, and present compressional stresses as indicated by seismic activity in the zone of overthrusts. That these forces might well have served to preserve the present anomaly-belt as a remnant of a much greater gravity-structure originating in any of the above ways must, however, be borne in mind, and for the present we can only speculate as to which phenomenon obtained, and reshape our ideas as new data accumulate.

Conclusion--The gravity-field in Virginia is believed to reflect three different conditions: (1) The surface or near-surface mass-density distribution resulting from variations in lithology as seen in the area adjacent to the Fall Line; (2) a lack of isostatic equilibrium resulting from sedimentation and compressional forces, or possibly a fundamental change from "continental" to "oceanic type" basement-rock; (3) a residual lack of isostatic equilibrium in the Blue Ridge Region from previous eras of crustal deformation and sedimentation, or deformation alone which has been maintained by subsequent crustal stress conditions.

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## ANNUAL REPORT OF PROGRESS OF THE GEODETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY

H. W. Hemple

During the past year the Division of Geodesy, United States Coast and Geodetic Survey, has received allotments for geodetic field-surveys from the Public Works Administration, in addition to funds normally appropriated. The Mississippi River Commission and the Soil Conservation Service, of the Department of Agriculture, have also transferred funds to the Division for specific surveys.

The allotment from the Public Works Administration for work in 34 States is in the amount of $490,000 and supplements the Survey's regular appropriation. The objective with these funds is (1) to complete those arcs of triangulation which were left unfinished when the expanded program on which the Survey was working during the years 1933-35 was suddenly stopped because of lack of further funds, and the completion of which will enable the adjustment of regional arcs of control, and (2) to relevel over certain lines of bench-marks for which discrepancies have developed, so that office adjustments of such work may be made.

Five double observing triangulation-parties have been in the field since July 15, 1938. Three of these have been steel-tower parties operating in the middle, western, southern, and eastern States, while two parties have been operating in the mountainous regions of the western States. It has been necessary to discontinue operations of the two parties in the West for a period from March 15, 1939, onward because of snow-conditions in the mountains which have made progress difficult. It is expected that these two parties will resume operations about May 15. All triangulation-parties will continue operations during the next summer and early fall and close work about September 1939, when funds will be exhausted.

The work done for the Soil Conservation Service consists of triangulation-surveys in the States of Utah, Colorado, and Arizona for control of air-photographs, to be used in studies for erosion-control made by that organization. One mountain triangulation-party was engaged on this work from May to October, 1938.

Two triple-unit level-parties have been in operation since July 15, 1938, and will continue until about May 15, 1939, when the funds provided for the leveling contemplated on this program will be exhausted.

The work done for the Mississippi River Commission consists of leveling in the alluvial valley of the Mississippi River between Head of Passes, below New Orleans, Louisiana, and Vicksburg, Mississippi, for use in connection with the flood-control program of that organization. Twenty river-crossings have been made in this stretch of the River. One triple-unit party was engaged on this work from March, 1938, to February, 1939.

The amount of work completed during April 1, 1938, to March 31, 1939, and the grand total to the latter date, are given in Table 1.

An astronomic party has recently started field-operations and will observe for determinations of latitude and longitude at Laplace stations on the arcs of triangulation recently com-

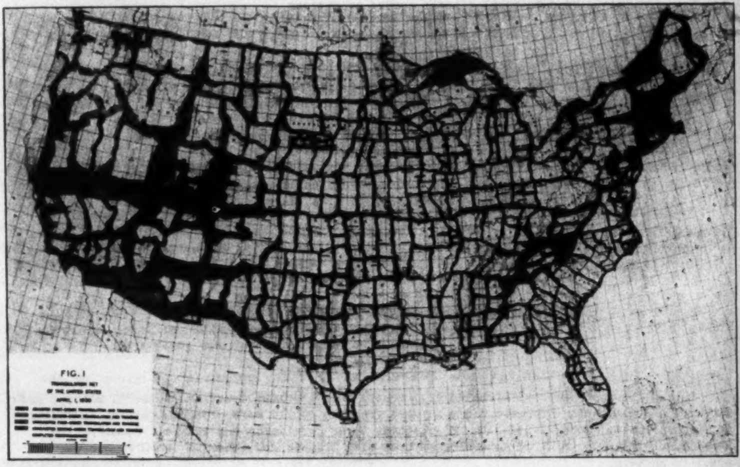

FIG. 1

TRIANGULATION NET OF THE UNITED STATES APRIL 1, 1939

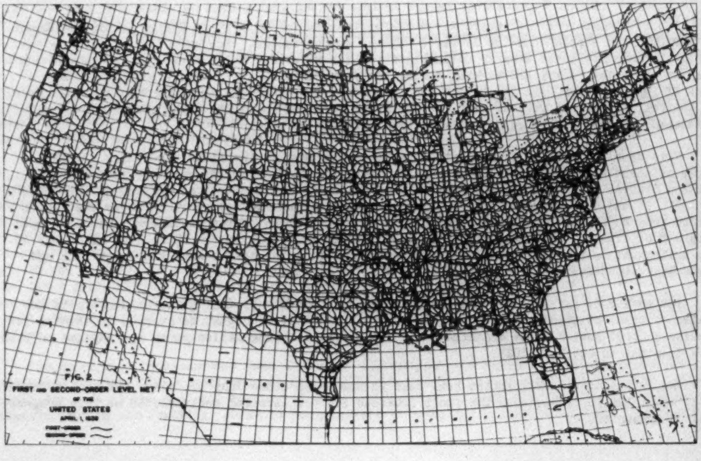

FIG. 2

FIRST AND SECOND-ORDER LEVEL NET OF THE UNITED STATES APRIL 1, 1939

Table 1--Work completed April 1, 1938, to March 31, 1939

| Item | Completed | | Grand total |
|---|---|---|---|
| | miles | stations | miles |
| Triangulation, first- and second-order | 6,000 | | 75,000 |
| Leveling, first- and second-order | 9,000 | | 272,000 |
| First-order base-lines | | | 210 |
| Second-order base-lines | | | 54 |
| Latitude-stations | | 2 | 842 |
| Longitude-stations | | 3 | 694 |
| Azimuth-stations | | 5 | 1,157 |
| Gravity-stations | | 130 | 1,020 |

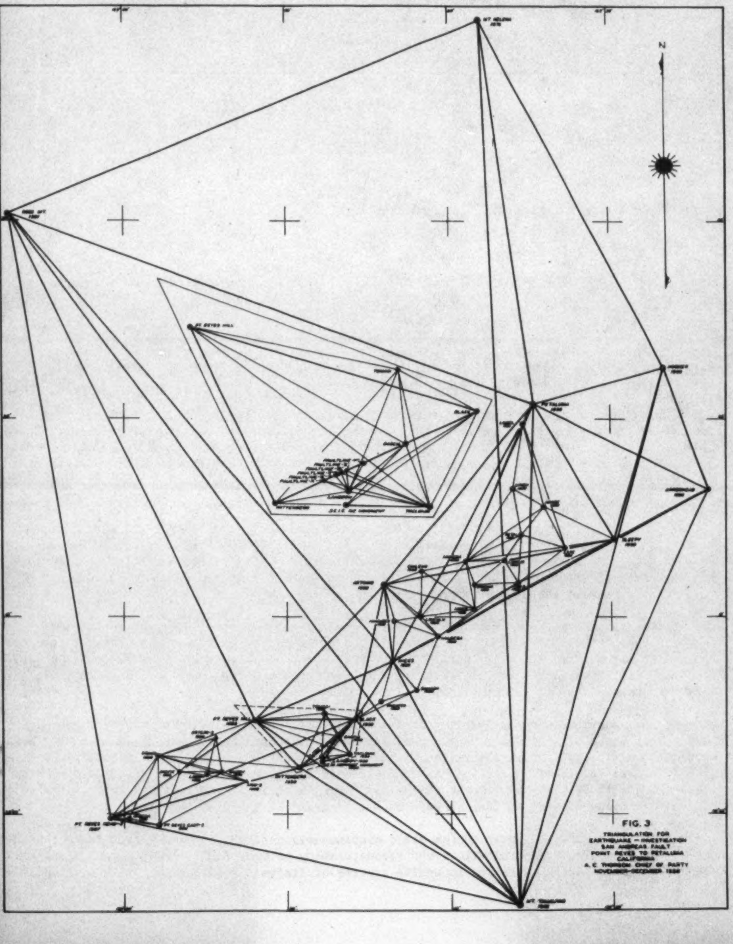

FIG. 3

TRIANGULATION FOR
EARTHQUAKE — INVESTIGATION
SAN ANDREAS FAULT
POINT REYES TO PETALUMA
CALIFORNIA
A. C. THOMSON CHIEF OF PARTY
NOVEMBER-DECEMBER 1938

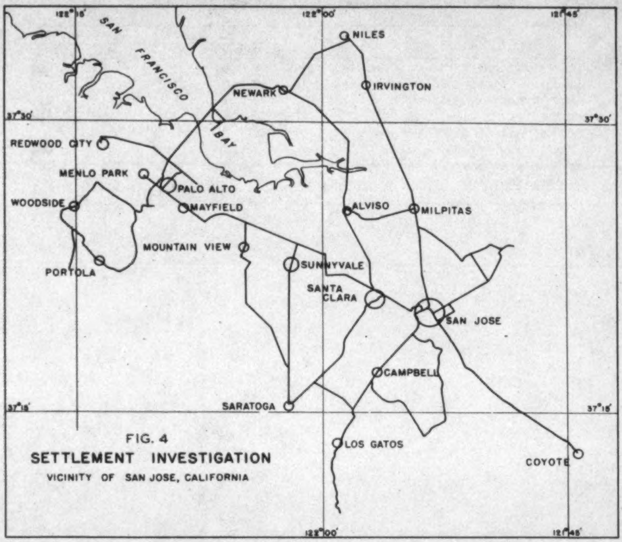

FIG. 4
SETTLEMENT INVESTIGATION
VICINITY OF SAN JOSE, CALIFORNIA

pleted. This will enable the office adjustment of these arcs to be completed and the final determinations of positions of stations to be made.

During the past year we have made repeat triangulation-observations for investigation of earthquakes in the area from Petaluma to Point Reyes, California. Stations on this scheme were originally established in 1930, and repeat-observations were made in December, 1938, to detect possible movements. The final adjustment of the work recently completed has not yet been made, but preliminary analysis indicates that no changes have occurred which would justify a conclusion as to general horizontal movements in this region.

In addition, during the past year we have established detailed control for earthquake-investigation purposes in three localities, near the towns of Maricopa, Gorman, and Palmdale, respectively, in Southern California. The general plan for this latter work contemplates the establishment of frequent control-points crossing the San Andreas Fault-Zone, over which triangulation- and traverse-surveys and leveling are executed.

The survey-lines extend about five miles on either side of the fault-lines, with monuments established about 100 feet apart the first mile, increasing thereafter as the distance from the fault-line becomes greater. The horizontal positions and elevations of these monuments are determined. It is planned that similar surveys, repeating the observations of last year, will be made over these lines in future years.

We have continued repeat-leveling in the Santa Clara Valley, in the vicinity of San Jose, in cooperation with the Works Progress Administration. Certain sections of this area have been subject to settlement during the past several years. At one place settlement amounting to more than five feet was found. Leveling has been repeated over certain lines on seven different occasions since 1933, the last running having just been completed. Indications are that the settlement has stopped, and the last surveys show a tendency of the area to rise.

One gravity-party has been in the field continuously during the year, except for short intervals required for standardizations and reconditioning of equipment. About 130 stations have been determined, partly as rather intensive studies of limited areas and partly as scattered

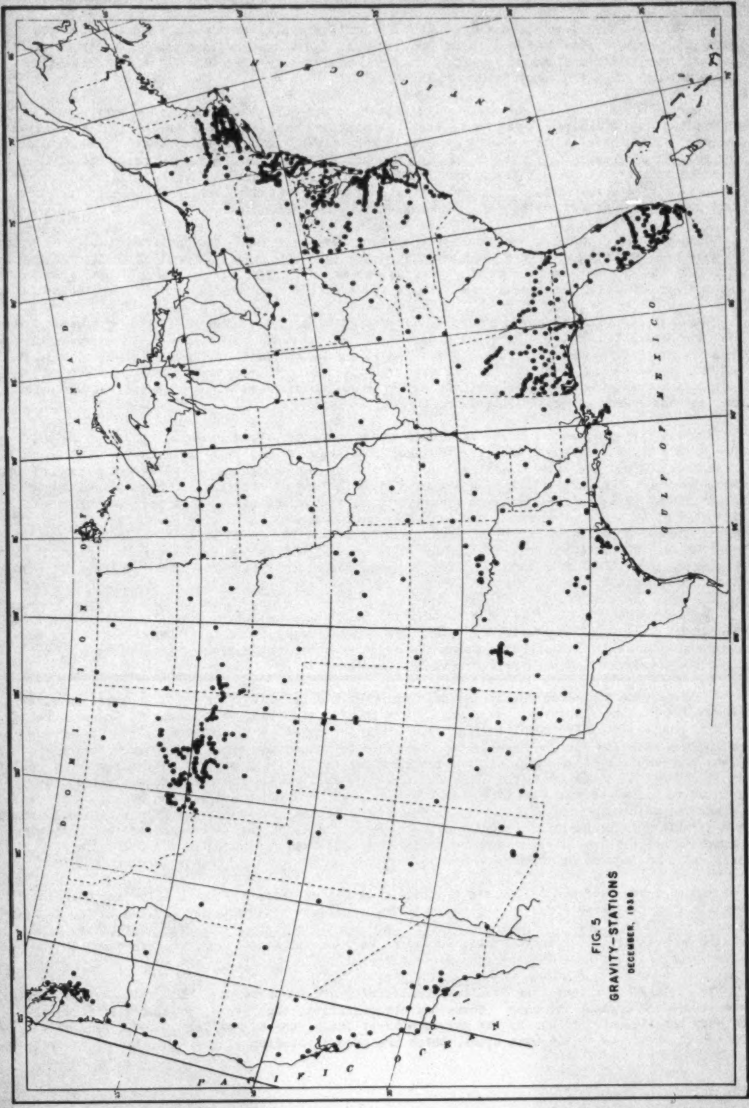
ATLANTIC OCEAN
DOMINION OF CANADA
GULF OF MEXICO
PACIFIC OCEAN

FIG. 5
GRAVITY-STATIONS
DECEMBER, 1938

stations to fill in some of the wide gaps in the general gravity-survey of the United States.

During the spring and summer of 1938, this party operated in Alabama, Florida, Georgia, Maryland, and New Jersey. The work in New Jersey included two profiles approximately at right-angles to the general trend of the coast-line and practically coinciding with the seismic profiles determined by Professor Ewing and Dr. Woollard.

During the fall of 1938 and up to the present, this party has completed a special project in southeastern Oklahoma, requested by the United States Geological Survey, and has established a number of scattered stations in the southwestern States. Two projects remain to be done of the present program, both at the request of the United States Geological Survey. One of these consists of a profile across the Sierra Mountains from Sacramento, California, to Reno, Nevada, which will be started soon. The other consists of two profiles in western Wyoming. The party will then return to Washington for standardization of equipment.

Experiments to improve the gravity-apparatus have continued. The specific problem on which we have been working has been a thermostatic device for temperature-control of the instrument to eliminate the temperature-correction. Indications are that this can be accomplished, although experiments are still being made to determine the effect of the heating currents on the pendulum.

We have continued the sponsorship of the computing office in New York City as a Works Progress Administration Project. About 150 people are employed in this office who have been selected from the unemployment relief-rolls. The work being done consists of the adjustment of triangulation, traverse, and leveling. It has been possible to do these complicated computations in this office principally because adequate supervision has been provided by several of our permanent personnel who have been assigned to this office.

In January, 1939, we organized an office in Philadelphia, Pennsylvania, sponsored by this Bureau as a Works Progress Administration project. About 75 men from the relief-rolls are at present employed. Adequate supervision is provided by the assignment of permanent personnel from our own Bureau. In this office we are typing descriptions of stations and bench-marks, geographic positions, plane coordinates, and elevations, so that these may be lithoprinted for general distribution. We are also making an index of geographic names appearing on our charts, determining the number of miles of shore-line bordering tidal waters, correlating tidal data at two stations on each of the Atlantic, Pacific, and Gulf coasts for the purpose of further study of the 19-year cycle of tidal phenomena, and coordinating seismological observations received from cooperating organizations.

We have continued cooperation with the King County Aerial Survey Project of the Works Progress Administration by furnishing technical supervision for the control-surveys. This project, operating in Seattle, Washington, has as its objective the preparation of assessment maps on which all property-lines will be correctly delineated.

We have also completed the fundamental horizontal control in Florida in cooperation with the Florida Mapping Project of the Works Progress Administration. Two of our field-men were assigned to supervise this triangulation. All other personnel were furnished by the Works Progress Administration. The work is in all respects up to the standards of accuracy prescribed for first- and second-order triangulation. The difficulties of doing work of this nature as a relief-project cannot be minimized. The personnel are subject to Works Progress Administration regulations as to number of hours of work permitted per week, the wages are low and do not permit of the men maintaining a home in addition to supporting themselves on the party; a very small amount is available for purchases of material and equipment. Without the assistance of this Bureau in furnishing supervision, steel towers, automobile trucks, and instrumental equipment, this work could not have been accomplished.

The assignment of one of our field-officers to act as technical adviser for the Georgia Geodetic Control Survey Project of the Works Progress Administration has resulted in the publication of a 1100-page book containing horizontal and vertical control-data for that State, comprising work of the Coast and Geodetic Survey as well as supplemental surveys executed by the relief-organization, based on the fundamental control.

The latitude-observatories at Ukiah, California, and Gaithersburg, Maryland, have continued in operation throughout the year. These two observatories, together with those maintained on the same parallel of latitude by the governments of Italy, the Soviet Union, and Japan, make similar observations of the same stars, which are used in studies of the variation of latitude.

The National Bureau of Standards has continued to cooperate by standardizing invar tapes for use in base-measurement and traverse-surveys.

Acts legalizing the use of the State plane-coordinate system promulgated by this Bureau, for property-description purposes, have now been passed in New York, Pennsylvania, New Jersey, North Carolina, and Maryland. Similar legislation is under consideration in Kentucky, Louisiana, and California, as well as in other States.

Among recent innovations instituted on our field-parties has been the requirement that at each concrete monument established along rural highways or on the rights-of-way of railroads, there be set a wooden post which projects at least 18 inches above the surface. This post is painted white and has the legend "U S B M", "U S A", or "U S REF MK" stenciled thereon. It is expected that the use of these posts will reduce the mortality of monuments which are established along routes subject to highway and railroad improvements, and which, in the past, have been unnecessarily destroyed. The posts will also be an aid to the recovery of the monuments, and the easier accessibility will bring about a greater use of the marks for local survey-purposes.

Demands for control-data have continued to increase. The utility and need for these surveys is becoming increasingly evident, and it is hoped that funds in sufficient amounts will be available so that this service to the public may continue on an intelligent and economical plan.

U. S. Coast and Geodetic Survey,
    Washington, D. C.

## GEODETIC WORK IN MEXICO DURING THE YEAR 1938

Manuel Medina

Triangulation--In the triangulation which extends along the Río Santiago, through the State of Nayarit, it was necessary to change a pentagon, transforming it to a hexagon with a central point, in order to locate a new station called El Crucero (Fig. 1).

Angular observations were made at stations Crucero, Las Animas, Huacales, Fileño, and Sanganguey, using at all these a Wild theodolite on which a measure of $0\overset{''}{.}2$ can be estimated.

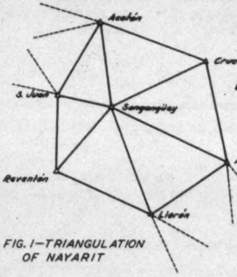

FIG. 1—TRIANGULATION OF NAYARIT

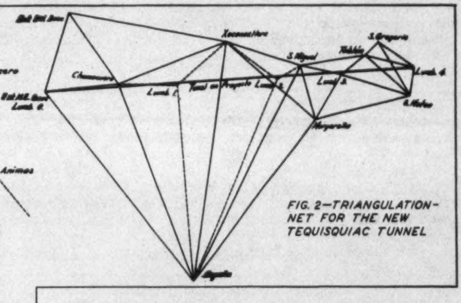

FIG. 2—TRIANGULATION-NET FOR THE NEW TEQUISQUIAC TUNNEL

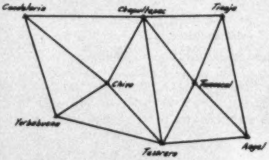

FIG. 3—TOPOGRAPHICAL TRIANGULATION IN ZACATECAS

In order to study the proposed new tunnel for drainage of the Valley of Mexico which at present the Secretary of Communications and Public Works is starting, this Office received the order to establish precise triangulation along the said tunnel in order to fix its axis and to proceed with the work of perforation. This triangulation includes 20 stations, at which directions were observed with a one-second Wild theodolite, and it depends on a short base, which was measured with an invar wire and found to be 1,726.8330 meters in length with a relative probable error of 1:2,000,000.

In the State of Zacatecas, the triangulation was extended by means of an auxiliary chain, which is connected with the geodetic line "Cerro del Angel-Tinaja" and which extends through the northwestern zone of the State, for the purpose of fixing control-points for topographic surveys (Fig. 3). This triangulation was observed with a Troughton and Simms 10-second theodolite, and its results are as follows: Average closure of triangles, 6"; average probable error of a direction observed 12 times, ± 2"; average linear closure in units of the 7th decimal place of logarithms, 556; mean error of an observation after adjustment, ± 7"; mean error of triangle-closure of the figures, ± 3".

Precise leveling--On the Mexico-Acapulco Highway, 83 km were leveled with a Berger instrument, Coast and Geodetic Survey type, and 11 monuments were established.

In the Valley of Mexico, levels were run from the fundamental bench-mark established in Tacubaya, D. F., through different circuits which cross Mexico City, for approximately 75 km. These operations have been made in cooperation with the "Mixed Commission for the Study of the Subsoil of Mexico City."

Gravity--The new gravity-stations established in the country and their results are given in Table 1.

Table 1--Results at gravity-stations in Mexico, 1938

| Station | g (observed) | Probable error |
|---|---|---|
| | gal | gal |
| Rio Verde, San Luis Potosi | 978.449 | 0.0006 |
| Ciudad Valles, San Luis Potosi | 978.725 | 0.0012 |
| Tampico, Tamaulipas | 978.801 | 0.0015 |
| Ciudad Victoria, Tamaulipas | 978.764 | 0.0005 |
| Monterrey, Nuevo Leon | 978.807 | 0.0008 |

Calculation of the topographic and isostatic compensation-corrections to the values obtained in Puerto México, Tuxtla Gutiérrez, Tonalá, Tapachula, Guatemala, San Salvador, La Unión, Tegucigalpa, and Managua has been continued and the rest will soon be started.

Traverses--Continuing the work for detailed surveys in the States of the Republic, traverses were run in Zacatecas with a total length of 574 km, using a theodolite on which an angle of one minute of arc can be estimated, and a 50-meter steel tape, effecting first the reconnaissance and azimuth-observation of the control-lines. These continue to depend on astronomical or triangulation-stations.

## Boundaries

Mexico-British Honduras--The line was completed and cleared between Monument No. 35 and Rio Azul, 13,460 meters in length, in which representatives from both Mexico and the English Colony took part.

Campeche-Quintana Roo--After meeting in the City of Mérida and approving the bases and program of work, the Commission proceeded to establish astronomical determinations of points shown in Table 2, using a two-second Repsold altazimuth and sextant.

Table 2--Astronomical determinations, Campeche-Quintana Roo Boundary

| Place | Latitude | Longitude |
|---|---|---|
| | ° ' " | ° ' " |
| Nohsayab | 18 44 07.9 | 89 14 04.5 |
| Halatún | 18 47 57.4 | 89 23 21.0 |
| Xcanhá | 19 06 12.7 | 89 20 05.5 |

Mexico-Guatemala--The Mexican Commission, appointed to trace the line between the two countries, established the 50-km traverse-survey along the parallel of 17° 49' with a one-minute Wild theodolite and a 50-meter steel tape and determined the astronomical positions with a sextant as shown in Table 3.

Table 3--Astronomical determinations, Mexico-Guatemala Boundary

| Place | Latitude | Longitude |
|---|---|---|
| | ° ' " | ° ' " |
| El Paixbán | 17 49 07.9 | 90 06 07.5 |
| Frontera | 17 49 40.8 | 89 56 48.0 |
| El Triunfo | 17 46 42.0 | 89 54 10.5 |
| La Lucha | 17 46 24.0 | 89 52 28.5 |
| Laberinto | 17 49 05.0 | 89 50 18.0 |
| Progreso | 17 49 36.0 | 89 48 27.0 |
| Villahermosa | 17 55 05.0 | 89 40 30.0 |

Dirección de Geografía, Meteorología e Hidrología,
Tacubaya, D. F., Mexico

AMERICAN GEOPHYSICAL UNION

Twentieth Annual Meeting

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# SECTION OF SEISMOLOGY

Washington, D. C.
April 27, 1939

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# THE MEETING OF THE INTERNATIONAL ASSOCIATION OF SEISMOLOGY IN SEPTEMBER 1939

N. H. Heck

In the past, while the preliminary program and agenda of the International Association of Seismology were well arranged, the program of daily meetings was made available scarcely a day in advance with resulting great inconvenience to those unable to be present at all times and especially those who might wish to attend other meetings at certain times. The Secretary, Dr. Rothé, has made a special effort to have the program for the Assembly at Washington in September 1939 arranged in advance, in spite of difficulties due to uncertainties regarding attendance in some cases.

The program includes: Addresses of President and Secretary, covering the activities of the past three years, the status of seismology, and outline of desirable program for the Association; national reports; financial matters and elections; discussion of items of agenda; and scientific papers of broad scope, usually not highly technical.

Before considering the program in detail, references are made to several matters of a general nature. The method of voting varies with the type of question. If financial, each country has a definite number of votes based on population (eight for the United States) which are cast by a single representative of each country, if necessary, after consultation with his colleagues. In the case of seismology the President of the Section of Seismology of the American Geophysical Union would cast the vote. In administrative matters each country has a single vote which is cast in the manner just described. In scientific matters provision is made for voting by delegates present, without regard to country. This has always been satisfactory but in the case of the United States, in view of the large numbers likely to be present in September 1939, courtesy requires that the number of members voting should not greatly exceed that for other countries. [Immediately after this paper was presented, the Section of Seismology took action to bring this about as recorded in the minutes on page 477.]

The International Association of Seismology differs from most of the other Associations in that it does not act--except to a very limited degree--through commissions or committees. While some Associations have probably carried the subdivision of work too far, it is probable that Seismology has not gone far enough. Even its Executive Committee scarcely functions to the extent provided in the statutes of the Association. I have investigated this matter and have found that the Committee, which is in part chosen for geographical reasons and which cannot continue for more than three years, is greatly handicapped in carrying out its functions. The result is that the Secretary, with some consultation with the President, has to make practically all the decisions. With due regard to the ability and conscientiousness of the present Secretary, this is not a wholly satisfactory arrangement.

The program is in part fixed by precedent and in part is the result of a circular sent out by the Secretary. In the case of the United States the local Secretary for the International Association of Seismology (Mr. Neumann) is charged with furnishing the information regarding the proposed program at the meeting of the Association in September 1939.

The program starts with the address of the President and the report of the Secretary. This year it is planned that the President will discuss problems and developments in world seismology and in the Association, and that the Secretary will deal with the history of the past three years in seismology.

Then comes the matter of business. An auditing committee is appointed, necessarily performing its duties in a perfunctory manner, since it cannot be appointed in advance, and questions of exchange alone would probably take all its time if carefully considered. In this connection, the placing of the funds in the proper country to avoid loss through exchange and devaluation is important and Dr. Rothé is entitled to great credit for his skill in this matter.

The principal and most lasting question is the division of funds between the "International Seismological Summary" and the Central Seismological Bureau at Strasbourg.

The "International Seismological Summary" was started at Oxford University, England, under the auspices of the Seismological Committee of the British Association for the Advancement of Science. Later the sources of funds became inadequate and the addition of many new stations and improvement of their quality greatly increased the number of earthquakes which could be located. The "Summary" has certain faults and some of the earthquakes are probably wrongly located, but it is the only complete list of earthquakes and has proved invaluable. It now receives half of the

Association's funds--a regrettably large part in view of the many useful things that might be done, but it is so important that it is to be hoped that the present arrangements may be continued. Both from the viewpoint of personnel and printing costs, it is a very economical arrangement.

In view of the relatively large contribution of the Association, an Advisory Committee of the "International Seismological Summary" has been appointed, one member of which has been selected by the Seismological Committee of the British Association for the Advancement of Science.

The other half of the funds goes to the Central Bureau of the Association and is expended by the Secretary, who is also Director of the Central Bureau. The funds are used for the following publications: Proceedings of the meetings, including the papers presented; monthly bulletin of the preliminary earthquake-epicenters; bibliography of seismology; and a series usually dealing with some broad phase of research in seismology. The funds also provide for maintenance of a library of seismology at Strasbourg. Special researches are supported in part. At present there are two, one by Miss Lehmann of Denmark and tne other (studies of wave-transmission, especially in the Atlantic Basin) by Professor H. Landsberg of Pennsylvania State College. At present the Central Bureau is getting out a list of seismological stations of the Earth, a successor to two similar volumes prepared under the auspices of our National Research Council, the first by H. O. Wood in 1921 and the second by H. E. McComb and Clarence J. West in 1931. This is really a proper international function.

Recent international events and especially the increased effectiveness of bombs from the air brought out consideration of the vulnerability of the Central Bureau of the Association at Strasbourg. It was agreed that any European site is at present subject to such risk and the variation between sites is only in degree. It is agreed that the Central Bureau must remain in Europe in order to serve its purpose.

The purpose of the principal expenditures has been explained since questions regarding them continually arise, sometimes to the extent of interfering with the scientific work of the meetings.

We now come to the scientific program. There are first the national reports which are usually published in advance and are available for distribution. It is customary for a delegate to give a brief resumé of his country's report.

Then comes the questions of the agenda. These are usually not numerous but often arouse debate and sometimes votes must be taken. If a vote is unanimous, the decision is generally adopted. If not, those voting in the negative do not necessarily adopt the decision even if there is a majority in its favor. Tnis is only reasonable because the system of voting is not entirely satisfactory and there is usually not time for arrival at a well-considered opinion. However, the very discussion often serves the purpose.

Then there is the matter of scientific papers. These are usually an expansion of matters discussed in national reports or in the agenda, though they may relate to neither. As stated, they are rarely purely technical. Finally, there may be special meetings of the Association or joint meetings with other Associations or Commissions. An example of the former was the memorial meeting at Stockholm, in honor of the great German seismologist, E. Wiechert, who had died shortly before. An example of the latter was the joint meeting at Edinburgh to form the Commission on Continental and Oceanic Structure, of which Dr. Field, President of the American Geophysical Union, is Chairman.

The program of entertainment related solely to the Association is usually that to be held on the afternoon of the second Wednesday afternoon of the Assembly. This is provided by the Section concerned.

U. S. Coast and Geodetic Survey,
Washington, D. C.

## AMERICAN GEOPHYSICAL UNION

Twentieth Annual Meeting

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# PRELIMINARY MEASUREMENTS OF OZONE OVER MOUNT EVANS, COLORADO

R. Stair and I. F. Hand

(Abstract)

The usual method employed in the study of the total amount of ozone above a given point has been that of measuring the intensity of the radiation at one or more wave-lengths within the ozone absorption-band, that is, below 3200 Ångstroms, relative to some longer wave-length or wave-lengths outside the region of ozone-absorption. Ordinarily a photographic method is utilized. Measurements are made at two or more different air-masses (air-mass equals approximately the secant of the Sun's zenith-distance) and upon the assumption that both the ozone-content and solar emission remain constant during the interval.

We doubt if either remains constant for a very long period and certainly both are definitely known to change in cycles, the ozone with the season [see 1 of "References" at end of paper] and the solar emission with the sunspot-cycle. Short periods of the order of days, hours, and possibly minutes, have been noted by others and also appear in the results of our own work at Mount Evans, where there was a definite variation in either or both the ozone-content or the spectral quality of solar emission in the ozone-band. It would be very difficult to separate the two effects, and we question if any of the present methods are sufficiently sensitive to accomplish this result. However, we feel that the effect of the change in solar emission within the range of wave-lengths reaching the Earth's surface--even upon a mountain top--is much less, and for the present may be neglected without making a serious error in the determination of the ozone above the observers.

High-altitude measurements minimize certain errors that are inevitable through the more vitiated lower atmosphere. Unfortunately, neither the observing period in July 1936, nor in July 1938, comprised many clear days. Especially on the tip of Mount Evans, high clouds or broken cumuli prevailed during the morning hours. On eight of the nine days spent at the crest in 1938, the cloudiness increased shortly after noon, on some days with startling rapidity, but on all eight days followed by rain, hail, sleet, and snow--generally in the order named. We were fortunate, however, in having less trouble from static than had been anticipated, but had prepared for this added trouble by observing with both our instrumental equipment and bodies well grounded by copper wire to avoid undesired fluctuations of the galvanometer-needle. At times the potential-gradient is so strong on Mount Evans that not only is the reading of electrical equipment impracticable, but the observer has to take advantage of the copper-roofed and copper-sided observatory to avoid uncomfortable sparking from his body to the ground.

The method of obtaining ozone here described makes use of titanium photoelectric cells and filters. Observations are made in the same manner as those reported by Coblentz and Stair [2] for the studies of ultraviolet intensities. For this work, however, a much more elaborate calibration of the photoelectric cell for spectral response and of the filters for spectral transmission is required than has been used in the study of total ultraviolet intensities.

The strong emission lines of both a mercury arc-lamp and a cadmium arc-lamp were used to obtain an equal energy-response at these wave-lengths during the calibration of the photoelectric cells. This is not sufficient, however, for wave-lengths longer than 3200 Ångstroms, which is close to the long wave-length limit in sensitivity of the cell. It was especially difficult to define the response between the wave-lengths 3261 and 3404 for the titanium cells used in this study. Since the response at 3404 was of the order of one ten-thousandth that at 2967 Ångstroms, extreme caution was necessary in the use of exclusion- and transmission-filters with the spectrometer to insure freedom from stray light of other wave-lengths. We were not satisfied with measurements made upon the weak mercury-line at 3340 Ångstroms for this reason. In use with solar radiation, these wave-lengths produce a large effect upon the total response of the cells and upon the total transmission of the filters; hence the great importance for knowing accurately the spectral response in this region.

Toward this end we set up a standard of continuous ultraviolet radiation in the form of a Mazda-CX lamp. This lamp approximates roughly the solar emission in the ultraviolet portion of the spectrum, having a high emission in the region where the photoelectric cells have a low response. By observing a set of transmissions of a group of calibrated filters with this lamp as a source, and by calculating the transmissions of the same filters from a knowledge of their spectral transmission, the spectral-energy emission of the lamp, and the spectral response of the photoelectric cell (based upon an arbitrary curve drawn through the values for the wave-lengths at which the response was determined spectroradiometrically), the shape of the photoelectric-cell response-curve, especially between 3261 and 3404 Ångstroms, was altered until the observed and calculated transmissions were in agreement.

The same filters, or duplicates, were used in our work at Mount Evans, as employed in the calibration with the Mazda-CX lamp. Their transmissions were determined at the wave-lengths of the mercury emission lines and the shapes of the curves between points adjusted for best agreement with calculations on other thicknesses of glass and integrated transmission-calculations in their use with the Mazda-CX lamp. We therefore feel that we have a good calibration of the filter-transmissions and that any errors will be partly balanced out by the fact that the Mazda-CX lamp has a spectral-energy emission curve in the ultraviolet spectrum somewhat similar in shape to that of sunlight.

Using four filters, measurements were made with two cells in July 1936 and with two other cells in July 1938. These data, transmissions in per cent, are plotted as a function of the solar air-mass at the time of the observations.

To obtain a measure of the amount of ozone at the time of the observations, we have proceeded by two methods. By the first method we have assumed a solar-energy curve outside the atmosphere. For this we have used observational data obtained by Pettit [3]. Starting with this spectral-energy curve we have by a process of integration (using 20 Ångstroms as a unit) calculated a set of transmission-curves for three of the filters having total transmissions of approximately 15, 40, and 60 per cent, as a function of solar air-mass. For these calculations we have used the Fabry and Buisson [4] transmission-coefficients for ozone and the Rayleigh scattering (atmospheric transmission) coefficients as used by O'Brien [5] in the reduction of the Explorer stratosphere balloon data.

While this method gives values which are roughly in agreement with the one described below, the calculated values indicate less ozone for the observations at noon and more for measurements in the morning and afternoon (high air-mass). Calculations on all the four photoelectric cells and the three filters (12 sets of observations) indicate the same type of discrepancy. Hence we conclude the Pettit curve is not sufficiently accurate for this purpose in that it is too low in value for the shorter wave-lengths. We have therefore by the second method, similar to that employed by Stair and Coblentz in their stratosphere work [6] set up our own solar-energy curve--not outside the atmosphere but within the range of air-masses covered by our observations. We first, by a method previously used by Coblentz and Stair [2] set up an approximate solar-energy curve for an air-mass near the noon hour (low air-mass) and "juggle" it until the calculated integral transmissions of the filters are in agreement with the observed values for some particular low air-mass. Then, having a spectral solar-energy curve which gives calculated transmissions in agreement with our observations for one air-mass, 1.06 for example, calculations are made for transmissions at other air-masses covering the air-mass range of observations, for different amounts of ozone. This gives a fan-shaped set of curves through the value for air-mass 1.06. The curve best representative of the observed data defines the amount of ozone above the observer at the time.

Having determined the amount of ozone for a particular day, and using the solar-energy curve in agreement with the observed data for air-mass 1.06, it is a simple matter to calculate the solar-energy curve for sunlight outside the atmosphere and from it transmission-values for other amounts of ozone other than the value in agreement with the data for that particular day, or days.

A set of calculations based on observations on July 20, 22, and 23, 1936, and evaluated in absolute units are in close agreement with Pettit's data from 3100 to 3250 Ångstroms. Above and below these wave-lengths our data indicate higher-energy values.

The method is not very accurate for the very short wave-lengths outside the Earth's atmosphere and which reach the Earth in low intensity nor for the longer wave-lengths to which the photoelectric cell responds, but for these wave-lengths the product of solar energy times cell-response is small and the effect upon the calculated ozone is therefore negligible.

To obtain more precise values in the shorter and longer wave-length regions several photoelectric cells having different spectral ranges should be employed.

For these same days our calculations indicate a fairly constant amount of ozone at about 0.20 (ntp) for July 20, and 0.18 cm for July 23. However, on July 22 the value was quite constant at 0.20 cm from early morning until $2^h\ 00^m$ p.m., when it suddenly decreased to about 0.18 cm, or slightly less by $3^h\ 00^m$ p.m., and then increased again to about 0.19 cm by $4^h\ 00^m$ p.m.

Consultation of the upper air-mass maps for July 22 indicates a change in air-mass, presumably at about the time that the ozone-content changed.

The preliminary calculations for a particular photoelectric cell and set of filters is quite complicated, but when these are once made it should be possible from a set of curves to determine the ozone-value from measurements with a single filter within a few minutes. This is a highly important factor should such measurements be used for forecasting purposes.

Because of the time required, we have not at this time concluded our calculations on all four photoelectric cells, but will publish the final results in the Monthly Weather Review shortly after July 1939.

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## THE PHOTOCHEMICAL ORIGIN OF ATMOSPHERIC OZONE AND THE CIRCULATION OF AIR IN THE LOWER ATMOSPHERE

Oliver R. Wulf

### (Abstract)

The existence of ozone in the atmosphere constitutes a meteorological phenomenon of much interest. There is reason for believing that the ozone originates in the photochemical action of solar radiation on the oxygen of the atmosphere. The acceptance of the photochemical origin of atmospheric ozone, which permits one to account for certain important aspects of the phenomenon, leads to interesting conclusions concerning the ozone of the troposphere. It has been shown (Wulf and Deming, Terr. Mag., v. 42, p. 195, 1937) that the active production of ozone by solar radiation occurs well up in the stratosphere, and that the regions below this are protected regions where solar radiation can neither form nor decompose ozone sufficiently rapidly to be of importance in affecting its distribution, under the conditions of the component concentrations existing in the atmosphere. It seems therefore that at least the principal portion of ozone of the troposphere has been transported there from regions in the stratosphere. Its existence in the troposphere and its variability are believed to be intimately connected with atmospheric circulation and turbulence. The meridional component of the circulation of air over the globe is taken to be a poleward overflow in the upper troposphere and an underflow over the Earth's surface toward equatorial regions. Circulation in the stratosphere is assumed to be such that its meridional component is the mirror-image of that in the troposphere. Such atmospheric circulation seems to lead to a distribution of ozone which varies with latitude and season, and in a manner which is in accord with experience. It seems also to be in accord with the observed relation between the temperature of the ozone and the value of its total vertical path.

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## METEOROLOGICAL RESEARCH IN CONNECTION WITH GROWTH OF TRANS-OCEAN FLYING

F. W. Reichelderfer

(Abstract)

Studies directed toward more complete knowledge of atmospheric circulation and its influence upon the behavior of LOWS are handicapped by paucity of observations over many large areas, particularly oceanic areas. While synoptic charts of the upper air are now fairly complete over the continental areas of Europe and the United States, there has never been available a sequence of synoptic charts showing simultaneous conditions in the upper air over a hemisphere, or over even as much as one-tenth of the globe if we refer to a sufficiently close network of observations to permit a positive analysis.

It is therefore of interest to investigators in this field to look over the proposed trans-ocean schedules for commercial aircraft, particularly in the Atlantic, and to estimate the accompanying extension of upper-air observations over the ocean. During the past ten years we have seen the phenomenal increase in aerological stations, including pilot-balloon stations and various types of airplane- and radio-sounding stations, over the continents induced by the needs of aeronautics. Operations of modern aircraft require frequent and well-distributed upper-air observations. These have served not only aeronautics but have given the data for important research studies in meteorology.

A preliminary survey of trans-Atlantic aircraft routes and the network of meteorological observations needed to support aircraft-operations, shows the gaps in our present system of weather-observations from vessels and indicates that from four to eight international "storm-patrol" vessels will eventually be needed in the North Atlantic to make observations and collect reports over areas which are at present inadequately covered. As visualized, these vessels would have functions with respect to air-navigation similar to the present functions of the International Ice Patrol vessel with respect to marine navigation. There are, of course, no definite plans for such vessels. Although the French have temporarily stationed a vessel, the Carimare, in mid-Atlantic in connection with their trans-ocean flight plans, the systematic development of the program will have to await international cooperation. Such vessels would be expected to take frequent upper-air soundings. These probably would be supplemented by similar soundings on board selected vessels plying the North Atlantic.

Test-flights based upon the principle of "flying the weather-map" indicate that eastbound flights will usually follow the shortest route, but westbound flights, because of their more frequent encounter with adverse winds and weather, will follow more devious routes. This again emphasizes the necessity for a widespread system of upper-air observations. A small start toward this system has already been made in the three-month program of radiosonde observations in the western part of the North Atlantic which is being carried on during the ice-patrol season this year. The extension of this oceanic network would furnish a wealth of material for fundamental research in meteorology.

U. S. Weather Bureau,
Washington, D. C.

## TWO IMPORTANT FACTORS CONTROLLING WINTER-TIME PRECIPITATION IN THE SOUTHEASTERN UNITED STATES

Jerome Namias

It has generally been assumed that most of the tropical maritime air responsible for the winter-time precipitation in eastern United States originates in the sub-tropical high-pressure cell of the North Atlantic. According to Bjerknes [see 1 of "References" at end of paper] this tropical air, in its trajectory around the south side of the North Atlantic HIGH, ascends and converges as it moves westward, so that a state of conditional instability is established. Bjerknes points out that the regions of most frequent shower-activity appear to be located in the western (particularly southwestern) portion of the sub-tropical anticyclonic cells, while the eastern portions, where descent of air is taking place, are characterized by deficient precipitation.

Rossby and Weightman [2], in a study of the synoptic weather-situation for the period February 16-19, 1926, were probably the first to point out the importance of conditional instability for warm front precipitation over southeastern United States. But they attempted to explain the conditional instability on a different basis than did Bjerknes many years later. Instead of ascribing it to thermodynamic processes taking place in the sub-tropical source region, they suggested that it was due to veering of wind with elevation so that progressively colder air from westerly regions would be carried over warm southerly air. This idea, also advanced by Humphreys [3] for the explanation of thunder-storms in the southeastern quadrants of cyclones, has not received the attention it deserves, and, in part, this can be blamed upon the faith meteorologists have placed in the assumption that air-masses are approximately horizontally homogeneous at upper levels. (From a careful study of "swarm"-ascents made by sounding balloons over Europe, Bjerknes and Palmén [4] have recently shown that there are appreciable horizontal gradients of temperature within air-masses, but that these are small compared to the gradients through frontal zones.) It is the purpose of this report to re-examine the problem of winter precipitation in southeastern United States in the light of these earlier ideas, and to expand them so that they can be of practical assistance in forecasting for periods five days in advance.

The daily analysis of aerological data over the United States has shown that many different vertical distributions of temperature and moisture may be observed in tropical maritime air-masses, while at the Earth's surface, these air-masses have essentially the same properties from one situation to another. Willett [5], for example, attempted to classify into frontal types the various observed stratifications of temperature and moisture, and concluded that the average characteristic values he gave in an earlier paper [6] for tropical maritime air-masses were not truly representative, for he had lumped together all cases in which tropical maritime air was found at the surface, while at upper levels dry superior air ($T_s$) rather than moist ($T_g$) was often present.

The fact that these tropical air-masses differ so widely in properties in the free atmosphere suggests per se that their origin cannot be attributed solely to one source region.

Some clues to the question of the source and properties of so-called tropical air have been suggested by the daily analysis of Northern Hemisphere charts and upper-air soundings over the United States. Numerous cases have been observed in which the polar front has moved far out over the North Atlantic, polar air drains into the trade-wind belt, and frontogenesis occurs just off the Gulf coast or off the coast of the Carolinas. Such frontogenesis normally takes place between the polar air-masses which have had a trajectory over the water and those which have taken a path which is mainly over the land. Two excellent examples of frontogenesis of this nature have been given by Byers [7]. During the past winter cases of such frontogenesis usually occurred following an outbreak of especially cold air at intermediate levels (about four km) over the northeastern United States.

On the basis of our experience with the Northern Hemisphere charts, it seems entirely possible that tropical maritime air-masses can be manufactured within a few days by the intense convective activity that must set in as deep cold polar air-masses move over the warm waters of the Gulf Stream and Gulf of Mexico. (When an especially cold polar outbreak occurs at Boston, one can see evidence of such convection in the Cunb clouds over the ocean within 30 miles.) This type of air-mass is unstable and showery, and is associated with lower than average "tropical-air" temperatures at upper levels. An extreme example of such a development is afforded by the period February 22 to March 1, 1939, in which air leaving the Continent at upper levels over Lakehurst and Washington was extremely cold (-38° minimum at 600 mb) over Washington. Shortly after this air-mass had left the Continent, extensive precipitation occurred over eastern United States, and the heaviest five-day tótals of precipitation for the winter season were recorded. The front between tropical and polar air is usually steep in such cases, and the temperature-difference between polar and tropical air is comparatively small. Soundings at Nashville, for example, frequently show that the tropical air is a few degrees colder than normal tropical-air temperature. The fronts, therefore, are mainly moisture-fronts, and not much ascent of moist air is required to produce precipitation. Since the air is unstable by virtue of its life-history the convection, once started, is assisted by the vertical temperature-distribution.

It appears possible, therefore, that some of our tropical maritime currents may be manufactured by convection in deep polar air-masses moving over the warm seas. It is interesting to note that in summer the same trajectory of polar air eventually leads to our dry and warm air ($T_s$) currents [8].

It is difficult, however, to give a physical explanation of such an anticyclonic trajectory of an extensive polar air-mass. Indeed, over the Continent, polar air-currents generally possess a cyclonic curvature, with the exception of small branches which are diverted around anticyclonic eddies on the right side of dominating cold air "wake-streams" [9]. While at present there appears no satisfactory explanation for this large-scale anticyclonic trajectory of polar air once it has left the Continent, no experienced synoptic meteorologist can doubt that it must be accepted as an observed fact.

TABLE 1—FORECASTS AND OBSERVED CONDITIONS, DECEMBER 5, 1938, TO MARCH 10, 1939

| DATE FORECAST MADE | ① FORECAST based on EL PASO SOUNDINGS | ② FORECAST based on LAKEHURST SOUNDINGS | ③ FINAL FORECAST from ① and ② | ④ OBSERVED PRECIPITATION Departure from Normal | ⑤ OBSERVED PRECIPITATION Amounts (inches) |
|---|---|---|---|---|---|
| Dec. 5, 1938 | − | − | − | − | .30 |
| 10 | − | − | − | − | .00 |
| 15 | − | − | − | − | .30 |
| 20 | − | + ✓ | N | N | 1.15 |
| 25 | + | + | + | + | 2.81 |
| 30 | − | − | − | − | .65 |
| Jan. 4, 1939 | − | − | − | − | .24 |
| 9 | + | − ✓ | N ✓ | + | 2.20 |
| 14 | + ✓ | − | N | N | .98 |
| 19 | − | + ✓ | N | N | 1.00 |
| 24 | − ✓ | + | N | N | 1.53 |
| 29 | + | + | + | + | 2.28 |
| Feb. 3 | + | − ✓ | N | N | 2.08 |
| 8 | + | + | + | + | 3.62 |
| 13 | + | + | + | + | 2.38 |
| 18 | + | + | + | + | 2.70 |
| 23 | + | + | + | + | 6.02 |
| 28 | + | − ✓ | N | N | 2.09 |
| Mar. 5 | − | − | − | − | .65 |
| 10 | − | − | − ✓ | N | 1.06 |

5-DAY PRECIPITATION NORMALS—ATLANTA + RALEIGH

| | | |
|---|---|---|
| DECEMBER | 1.34 | inches |
| JANUARY | 1.39 | " |
| FEBRUARY | 1.56 | " |
| MARCH | 1.48 | " |

The question next arises as to what temperatures aloft are necessary to allow convection over the Atlantic to penetrate a fairly deep stratum. If we arbitrarily choose the 600-mb surface as that level to which convection must proceed to form a significantly deep moist air-mass, then we may estimate the temperature at this level that must be exceeded in order for air following a trajectory over the Gulf Stream to permit convection through this level. Using the value of mean winter pressure in this area given by Shaw [10], and the temperatures of the surface-water in the Gulf Stream by Slocum [11], and assuming a dry adiabatic lapse rate, we find that this "critical" temperature is -18° C.

Making the preliminary assumption that all air leaving the Continent over Lakehurst undergoes the anticyclonic motion suggested, we might guess that if the temperature at 600 mb over Lakehurst drops below -18°C in any one day (or more) of a five-day period, the succeeding five-day period would be characterized by above-normal precipitation in southeastern United States, otherwise by sub-normal precipitation. During the past winter the application of this simple rule for successive five-day periods would lead to nine forecasts of greater than normal precipitation in the southeast in the forecast period beginning December 5 and ending March 10, and eleven forecasts of less than normal. These forecasts are shown in column 2 of Table 1. Verifying the forecasts on the basis of the total precipitation at Atlanta and Raleigh (column 5), there were 15 forecasts correct and five incorrect. While it is quite clear that this factor alone cannot explain all periods of above normal rain, in view of the better than chance result, it would seem that it may play a part.

Some support for this suggestion may be found in the departures from normal precipitation observed in southeastern United States in the month of January 1936. These departures are shown in a chart (Fig. 1) reproduced from the Monthly Weather Review. The extensive northeast-southwest alignment of excess precipitation suggests a similar alignment of the polar-tropical air-front a good part of the time with a number of cyclones moving toward the northeast along the polar front. The tracks of centers of cy-

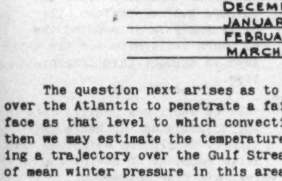

FIG. 1—DEPARTURE OF PRECIPITATION FROM NORMAL, JANUARY 1936

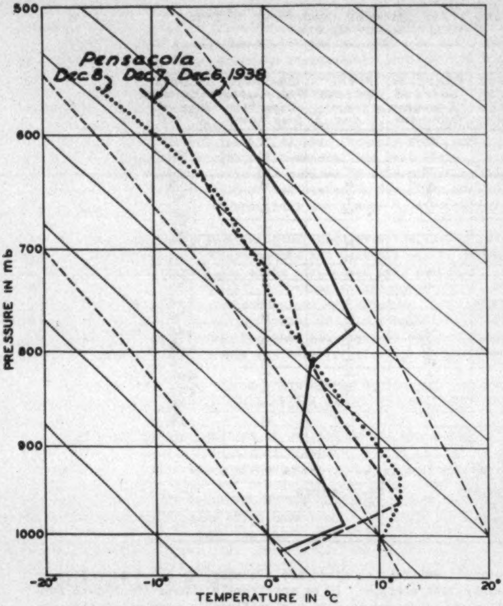

*FIG. 2—LAPSE-RATES OBSERVED OVER PENSACOLA, FLORIDA*

clones for the month, as shown in the Monthly Weather Review, bear this out. But whereas one might expect the upper levels over Pensacola to be warmer than normal in the mean with more than the normal supply of tropical Gulf-air aloft, they are slightly below normal (for example, departures from normal of -1°1 C at 2000 meters and -1°8 C at 5000 meters). There were 27 ascents made during this month, enough to insure a representative average. Similarly, at Washington the mean temperature for the month averaged 3°2 C below normal at 2000 meters and 3°8 C below normal at 4000 meters. While this evidence is not by any means conclusive, it seems to lend support to the suggestion that the tropical air east of the polar front was formed by intense convection occurring in abnormally cold outbreaks leaving the Continent over the North Atlantic States and later on recurving anticyclonically over the warm waters of the Gulf Stream and eastern Gulf of Mexico. The daily analyses of maps of the Northern Hemisphere for the month seem to support this interpretation.

We shall now inquire into the possible use of the suggestion by Rossby and Weightman that large supplies of energy can be stored up by cold air from the west moving over progressively warmer air from the south.

As an illustration of the importance of this type of action, the weather-situation of December 6 to 8, 1938, has been chosen. In Figure 2 are shown the soundings made during this period at Pensacola, Florida. Considering the entire column of air from the surface to the top of the ascents, a remarkable change in the vertical stability takes place between December 6 and 7. At levels above 810 mb there is a drop of temperature amounting roughly to 6°C, while below this level there have been equally large increases in temperature. This change in the lapse-rate would indicate that cold air has been brought in aloft while warmer air has been transported in the lower layers. This "differential" advection is best shown by the isentropic charts (Figs. 3 and 4) for two surfaces of constant potential temperature (290° and 300°). In the lower isentropic surface (Fig. 3) a tongue of moist and warm air is observed flowing northeastward over the east Gulf States. Aloft, however, the axis of this moist tongue is shifted eastward, and has been displaced by the tongue of cold and dry air from the west.

The store of potential energy thus built up finally breaks down on December 8 when thundershowers are observed in northern Florida.

Such a reversal of temperature-changes with elevation generally characterizes an upper cold-front, a phenomenon discussed in some detail by Rossby and Weightman [2], and later by Lichtblau [12] and Holzman [13]. As the latter authors point out, the upper fronts are often characterized at the surface by isallobaric discontinuities, although these are not always distinct. But a fundamental difference of opinion arises in connection with the precipitation produced by such fronts. Whereas Holzman and Lichblau would attribute the precipitation entirely to the lifting action on the warm air ahead of the advancing upper cold-front, Rossby and Weightman believe that advection of colder above warmer air provides a mechanism for storing up potential energy in the

**form of conditional instability. The release of this instability, they suggest, is chiefly responsible for the irregular precipitation which occurs from warm fronts in southeastern United States.**

**While there can be little doubt that upper cold-fronts of the warm-front occlusion-type are dynamically significant in producing precipitation, as Holzman and Lichblau suggest, it would seem to the author that cold air advancing over air which is flowing from the south over the Gulf States most frequently leads to instability showers, which are set off through the action of insolational heating from below, or at night, by radiational cooling above [14].**

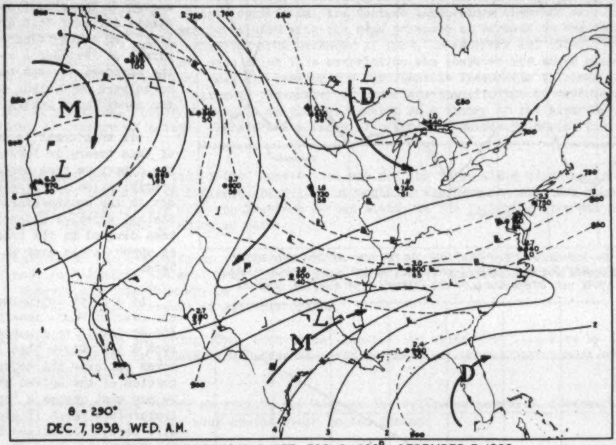

*FIG. 3 — ISENTROPIC CHART FOR θ = 290°, DECEMBER 7, 1938*

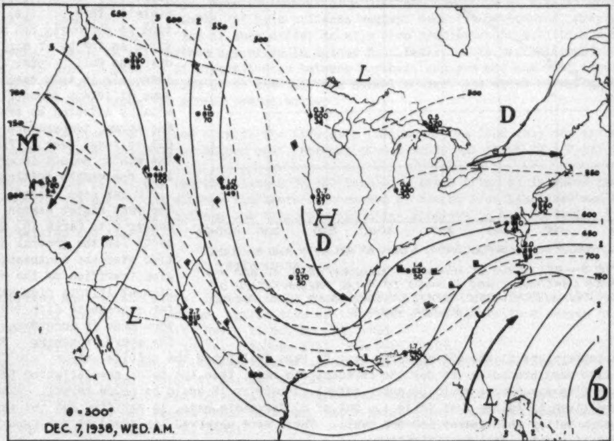

*FIG. 4 — ISENTROPIC CHART FOR θ = 300°, DECEMBER 7, 1938*

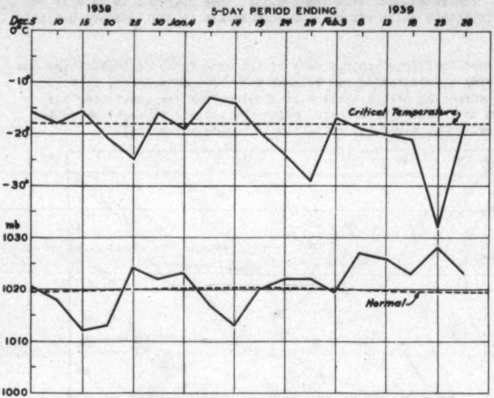

FIG. 5—MINIMUM TEMPERATURE OBSERVED AT 600 mb OVER LAKEHURST (UPPER CURVE) AND FOLLOWING 5-DAY MEAN PRESSURE AT BERMUDA (LOWER CURVE) FOR WINTER, 1938-39

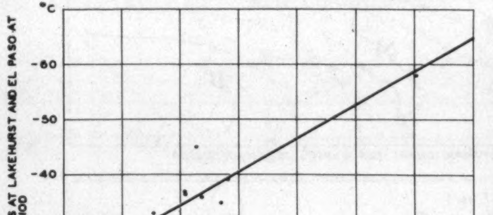

FIG. 6—RELATION OF MINIMUM TEMPERATURES AT 600 mb OVER LAKEHURST AND EL PASO TO TOTAL PRECIPITATION OF SOUTHEASTERN UNITED STATES, SUCCEEDING 5-DAY PERIOD FOR WINTER, 1938-39

In the case mentioned above, there seems to be some evidence that the showers produced on December 8 at Pensacola and Apalachicola, Florida, were the simple result of heating the surface-air to temperatures sufficiently high (66° at Apalachicola) to release the stored-up energy in the conditionally unstable air over this area. At least, an energy-diagram for the ascent on December 8 shows that the observed maximum temperatures were sufficient to release the conditional instability aloft.

In an attempt to make use of this theory in forecasting the departure from normal of the precipitation for five-day periods in the southeastern United States, especial attention has been devoted to the temperatures at upper levels over El Paso, Texas.

As a first approximation the air over El Paso, namely, at the 600-mb level, is assumed to take such a trajectory that it always moves out over the southeastern portion of the United States. We now must choose a "critical" temperature which if exceeded will permit convection to reach the 600-mb level as the air moves over the southeastern states. This critical temperature is obviously not as easily fixed as for polar air moving over the Gulf Stream, for the lower air in this case may assume different temperatures vitally affected by insolation. The normal temperature for the 600-mb level over El Paso for the winter season is around -5°C. As a reasonable critical value -10°C has been chosen. During the past winter season from December 5 to March 10, 20 forecasts for the general precipitation over the southeastern region (verified by the precipitation at Atlanta plus Raleigh) for successive five-day periods were made in accordance with the above reasoning. If the minimum temperature at the 600-mb level over El Paso fell below the critical value (-10°C) on any one of five days preceding the day the forecast was made, then the total precipitation for the following five-day period would be above normal, otherwise it would be below normal. These forecasts are given in column 1 of Table 1. Out of 20 forecasts made, 18 verified and two failed, a result much better than chance (50 per cent). There were observed ten cases of sub-normal and ten cases of super-normal precipitation.

Applying the same method to the polar air leaving the Continent over Lakehurst for the same periods, we found five forecasts of the 20 wrong, and 15 right.

It will be remembered that Rossby and Weightman's theory suggested two conditions necessary for the creation of conditional instability, namely, the advection of warm southerly air, and, above this, advection of colder air from the west. The southerly flow is naturally stimulated when the Bermuda HIGH is most intense, and is weak or completely lacking if the Bermuda HIGH is not well developed. Empirically, it was noted by the author that flows of polar air which are unusually cold at upper levels are followed by a building up of the Bermuda HIGH. In order to apply a more quantitative test of this empiricism, the minimum temperature observed over Lakehurst during a five-day period was correlated with the mean pressure at Bermuda in the following five days during the period extending from December 1, 1938, to February 28, 1939. The correlation was -0.56, and the values upon which this correlation was computed are shown graphically in Figure 5. It would appear that cold air leaving the Continent is frequently followed by building up of the Bermuda HIGH, although the number of cases are insufficient to definitely establish the correlation. (Prof. Rossby is at present working on a theory of the distribution and movement of centers of action, which shows promise of offering a better criterion for the Bermuda HIGH.)

Assuming that the correlation holds, however, we may use the temperature of the air leaving the Continent over Lakehurst to indicate the future strength of the Bermuda cell, and hence the strength of the southerly flow over southeastern United States in the following five-day period. The mechanism, then, is one in which we have:

(1) Cold polar air intensifying the Bermuda HIGH, which
(2) Acts to intensify the southerly flow in lower levels over the southeastern United States, and this flow may be
(3) Overrun by cold currents of westerly origin.

These three factors may bring about conditional instability which when liberated by the action of the polar front (or insolational effects) gives southeastern United States most of its winter-time precipitation.

With the help of this theory we finally may suggest the following method of forecasting the five-day precipitation in winter over southeastern United States:

When forecasts based on the critical temperatures (-18°C at Lakehurst and -10°C at El Paso at the 600-mb level) agree in sign, then there will be a distinct departure of precipitation in the indicated direction. For example, if both criteria suggest negative departures, precipitation will be well below normal, and if they differ in sign then precipitation will be about normal. Forecasts based on this method are given in column 3 of Table 1. We may reasonably consider "normal" to take in amounts of precipitation between one-half and one and one-half times the normal, less than normal to include up to one-half the normal amount, and above normal greater than one and one-half times the normal precipitation.

Checking the observed (column 4) with the forecasts (column 3), we find only two errors out of 20 forecasts, or an accuracy of 90 per cent, whereas chance would net about 33 1/3 per cent.

We may further illustrate the correlation in the form of a graph (Fig. 6) in which the ordinate represents the sum of the minimum temperatures observed at 600 mb over Lakehurst and El Paso in a five-day period, and the abscissa the total precipitation observed in the following five-day period at Raleigh and Atlanta.

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## SOME UPPER-AIR OBSERVATIONS MADE IN THE PACIFIC

W. M. Lockhart

For many years the Navy has made upper-air observations at their various air-stations but observations at sea were few and far between, chiefly because of the great amount of work required to launch and land a single airplane on a carrier. Commanding Officers were loath to burden their crews with the additional work required to shift airplanes all over the flight-deck, for the launching and recovery of one airplane was practically as much work as 75 airplanes.

In recent years with the increased interest in weather-information in the Fleet and the support of various admirals in command, the ship aerological units have been able to obtain a few consistent daily soundings. With the aim of bringing some of this information out into the light of day before it gets too deeply buried in the files, I have prepared a composite picture of some of the observations made in the Pacific.

In order to illustrate these soundings, I have prepared charts of potential temperature and specific humidity and have superimposed these charts over a plot of the ship's position where these soundings were made. It is recognized that this method is in no way comparable to an instantaneous cross-section of the atmosphere between two or more places as is now done in the United States, nor is it possible throughout to obtain an authentic picture of the slope or orientation of the isentropic surface, for thus far it has been impracticable to place our ships where we want them.

Figure 1 illustrates three soundings taken between the Canal Zone and the equator in May 1936. It is with regret that no sounding could be obtained on the equator on May 20, but with no blind flying or homing equipment on the plane it would have been quite risky for skies were completely overcast with strato-cumulus with a ceiling about 1200 feet the entire day.

These soundings are of especial interest in that they were taken across the boundary-zone between the northeast and the southwest trades. At this period of the year, this zone is found in the vicinity and just south of Cape Mala, Panama. The line of soundings is practically along the prevailing wind flow so that the chart represents approximately isentropic flow. The lines of potential temperature indicate a weak cold-front structure with the cooler southwest trades under-running the warmer north and northeast trades.

Many of you have read Lt. Comdr. True's article on typhoons which appeared in the Naval Institute in 1936 and have heard him elaborate on his observations at a lecture given at the Weather Bureau last summer. It was his contention that the southwest trades were the source of the cool air in a typhoon and that the northeast trades were warm and dry. In this connection I wish to point out that many hurricanes form in the area some 200 to 600 miles north of where these soundings were taken, usually in June, July, August, and September, probably along the boundary-zone between the southwest and northeast trades. In fact between June 6 and 8 in the year of these soundings such a hurricane formed in the Gulf of Tehauntepec. I am of the opinion that there is great truth in Lt. Comdr. True's statement regarding the southwest trades being the cooler of the two currents of opposing air and I offer these soundings as probably the first real instrumental proof.

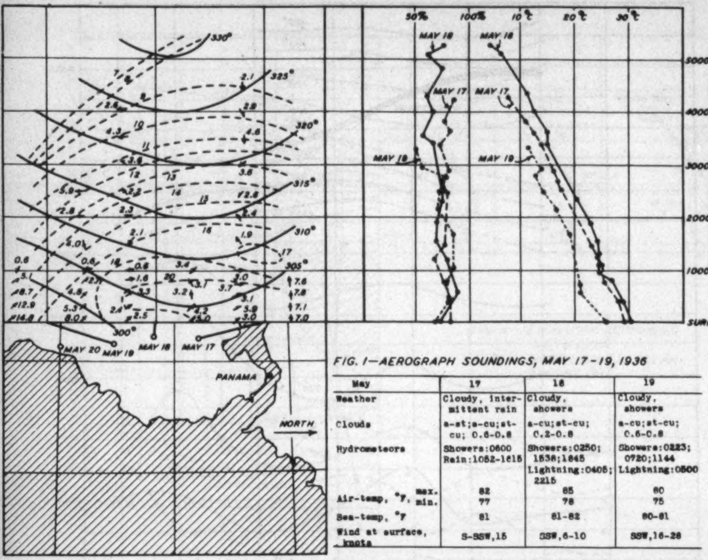

FIG. 1—AEROGRAPH SOUNDINGS, MAY 17-19, 1936

| May | 17 | 18 | 19 |
|---|---|---|---|
| Weather | Cloudy, intermittent rain | Cloudy, showers | Cloudy, showers |
| Clouds | a-st;a-cu;st-cu; 0.6-0.8 | a-cu;st-cu; 0.2-0.8 | a-cu;st-cu; 0.6-0.8 |
| Hydrometeors | Showers:0600<br>Rain:1052-1615 | Showers:0250; 1538;1645<br>Lightning:0405; 2215 | Showers:0223; 0720;1144<br>Lightning:0500 |
| Air-temp, °F, max. | 82 | 85 | 80 |
| Air-temp, °F, min. | 77 | 78 | 75 |
| Sea-temp, °F | 81 | 81-82 | 80-81 |
| Wind at surface, knots | S-SSW,15 | SSW,6-10 | SSW,16-28 |

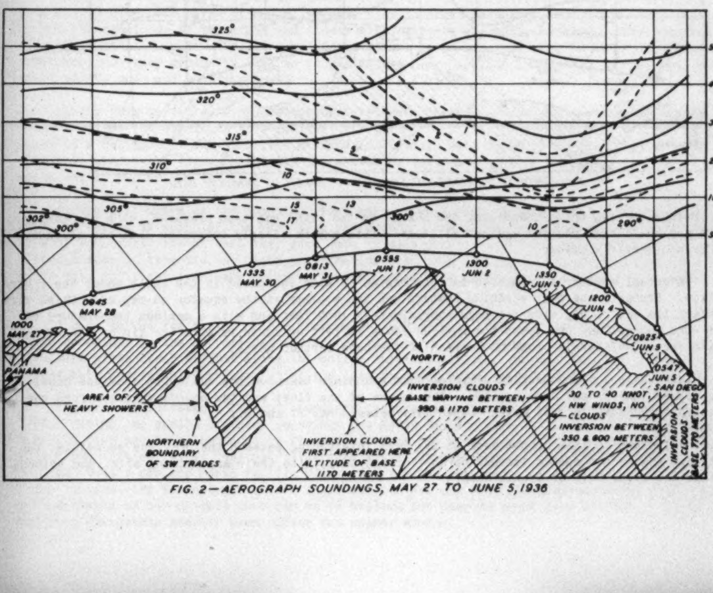

FIG. 2—AEROGRAPH SOUNDINGS, MAY 27 TO JUNE 5, 1936

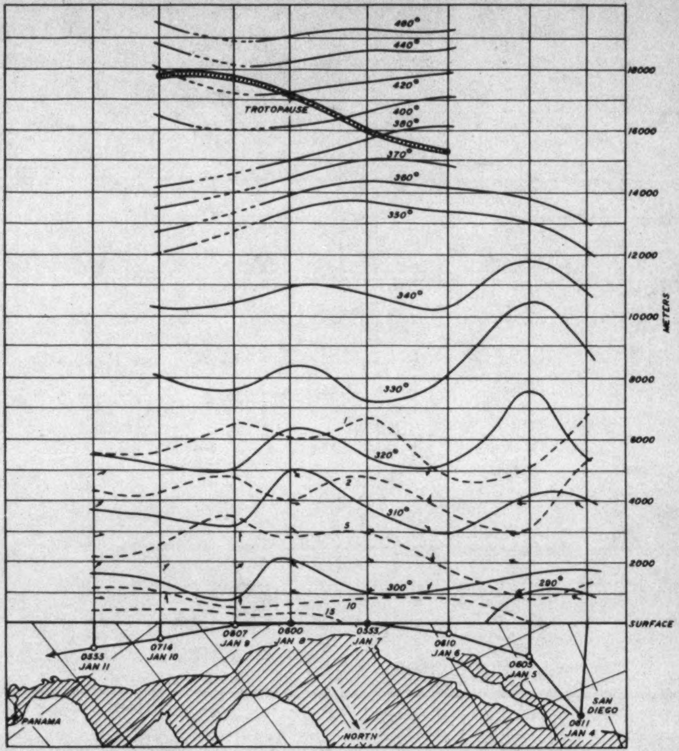

FIG. 3—COMPOSITE CHART OF SOUNDINGS TAKEN IN JANUARY 1939

Before leaving these soundings, the sketch on the right has been prepared, with the temperature and humidities plotted against altitude. This sketch clearly indicates that the southwest air is considerably colder.

The actual weather encountered in this region is also indicated in the table under the cross-section. Probably the most striking feature was the weather at the equator on May 20. Skies were overcast the entire day with ceilings approximately 1200 feet and with a maximum temperature of 73°F--the coolest day the fleet encountered since it left or again reached the tip of the Peninsula of Lower California--some 23 degrees of latitude farther north.

Figure 2 is a cross-section prepared from soundings taken on the way north from the Canal Zone between May 27 and June 5, 1935. The course of the fleet and the soundings are across the isentropic surfaces in some cases, especially between May 27 and 31.

One feature is that in the week to ten days intervening between the previous soundings, the southwest trades had pushed farther north--in fact they, with their accompaning area, had extended into the lower Gulf of Tehauntepec.

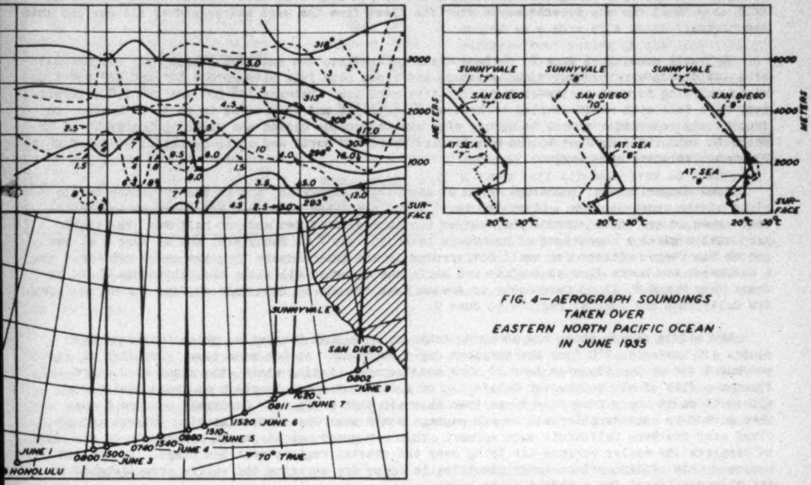

FIG. 4—AEROGRAPH SOUNDINGS TAKEN OVER EASTERN NORTH PACIFIC OCEAN IN JUNE 1935

Another striking feature was the encountering of typical inversion-clouds as far south as Acapulco, Mexico, the night of May 31. These clouds formed between 9 and 10 p.m.--sky remained cloudy the remainder of the night and clouds dissipated in the early morning. This occurred each night until June 3--with the base of the clouds at an altitude of 1170 meters the first night and then they gradually lowered to 990 meters near Cape San Lucas with surface and upper winds mostly west and west-northwest.

During this period a 29.50 LOW was centered over Chihauhau, Mexico, with the center of the North Pacific HIGH displayed well south of its normal position. There are some slight indications of a weak cold-front structure on June 1. Between June 3 and 5, strong to gale-force northwest winds were encountered with inversions of temperature aloft amounting to from 3° to 8° C above 350 to 600 meters' altitude.

Figure 3 illustrates the soundings that were taken during January 1939 by the fleet en route south to Panama by means of the Navy-type radiosonde. There are few features to discuss on this line of soundings, except that they gave data to much greater altitudes than airplane flights--although some of them did not reach the stratosphere. The problem of launching a radiosonde on board ship still requires considerable finesse, especially if the ship is making any apparent wind.

I have marked the height of the tropopause in Figure 3. The most striking point to me about these soundings is the extreme dryness of the atmosphere all the way south from San Diego. This structure gives clear weather along the entire coast of Mexico. Showers were not encountered during this cruise until the day after the last sounding shown in Figure 3.

Figure 4 illustrates a line of soundings taken between Honolulu and San Diego during June 1935. During the period of these soundings the North Pacific HIGH cell was in the process of breaking down and being replaced by fresher air from the west--thus I wish to point out that this cross-section really does not illustrate a well-established and long-lasting phenomenon as we might expect for the North Pacific HIGH. But I might here add an observation which should be borne in mind--the North Pacific HIGH cell, as with all mid-latitude semi-permanent HIGHS, is not as stable as our normals have led us to believe but they do break down and build up again and give changeable weather even during the summer months.

The last few days of this cruise are of considerable interest. The fleet had been steaming along just ahead of a trough between June 4 and 6. On June 6 an alto-cumulus cloud-sheet with 6/10 to 8/10 of the sky covered moved over the fleet from the west and persisted all day and into the night.

By early morning of June 7, surface-winds backed into the south-southeast--sky was overcast with low clouds strato-cumulus and stratus--and light rain fell between $03^h\ 00^m$ and $08^h\ 30^m$ with winds shifting to west-northwest but velocities were low. Between $13^h\ 20^m$ and $15^h\ 15^m$ intermittent rain fell with winds veering to northwest and north and freshening to 15 to 20 knots. On June 8, sky remained overcast to cloudy with strato-cumulus clouds and winds northerly 20 to 26 knots in velocity. By June 9, the clouds dissipated and north and north-northeast winds of 25 to 30 knots' velocity were logged.

Some comparisons of soundings taken at San Diego, Sunnyvale, and at sea are shown to the right of the cross-section. First the three soundings taken on June 7 are shown on the left--that taken at sea shows considerably colder air in the first two and one-half km. The right-hand sketch gives a comparison of soundings taken on June 7 at Sunnyvale, and on June 9 at sea and at San Diego. Except for small differences in the lower layers they are quite similar. As a northwest and north flow at surface and aloft was reported all along the California Coast between June 7 and 9, it is reasonable to assume that the air at Sunnyvale on June 7 covered Southern California and coastal regions on June 9.

The middle sketch shows the sounding taken on June 8 at Sunnyvale, which indicates much cooler air averaging 7°C from the previous day's sounding. At the same time, soundings at sea on June 9 and at San Diego on June 10 show considerable heating aloft--the upper-wind chart indicates a flow of air south over California of sufficient speed to reach Southern California within 16 to 18 hours from June 8, so that this air that moved over Sunnyvale on June 8 must have picked up considerable heat on its passage south over the heated interior valleys and arrived over Southern California much warmer. This air moved out aloft and appears to be too warm to displace the cooler surface-air lying over the coastal regions near San Diego. But it did compress this cooler surface-layer resulting in dense fog covering the entire area eastward of San Clemente Island for a period of 36 hours.

U. S. Navy,
Navy Department,
Washington, D. C.

## RELATIONSHIP OF LOW TEMPERATURES ALOFT TO PRECIPITATION

A. K. Showalter

Detailed analyses of a number of flood-producing storms have revealed a dominant tendency for heavy persistent rains to occur along a quasi-stationary front which lies just to the east of a deep cold air-mass having a cyclonic circulation.

An attempt has been made to develop a generalized explanation for this relationship on the basis of theoretical and observational evidence regarding the circulation in the vicinity of an air-mass boundary-region or frontal zone.

Attention is first drawn to the relative effects of the thermal component in (1) a cold air-mass with a steep lapse-rate and (2) a warm air-mass having a moderate lapse-rate but being potentially convectively unstable. If the warm air-mass lies above and to the east of the colder air-mass, the effect of the thermal component will be to cause an increasing cyclonic circulation with increasing altitude. The generalization made is that such an arrangement of air-masses will produce an upslope component of the warm air and cause it to undergo convergence. The effects of convergence will render the warm air-mass actually unstable. As long as convective currents are active in the warm air-mass which is moving upslope, it is assumed that the vertical velocities will be sufficient to hold the condensed water in suspension. However, when any air-mass tends to move upslope a number of factors usually combine to cause it to undergo vertical convergence, horizontal divergence, and a deflection to the right of its initial direction of flow. When the convergent tendency is overcome by these latter forces, the air-stream will curve to the right downslope, and the reduced vertical velocities may permit some of the suspended droplets to fall as rain. Regions of pronounced convergence aloft are assumed to be associated with anallobars at the surface with perhaps some divergent flow in the surface-layers. Areas of pronounced divergence aloft are assumed to be associated with katallobars at the surface-layers with perhaps

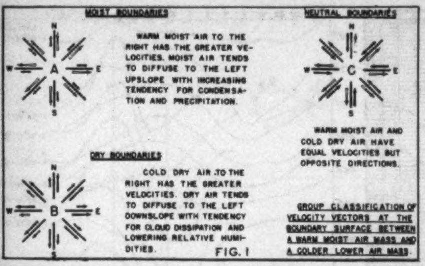
MOIST BOUNDARIES
N
W
A
E
S
WARM MOIST AIR TO THE RIGHT HAS THE GREATER VELOCITIES. MOIST AIR TENDS TO DIFFUSE TO THE LEFT UPSLOPE WITH INCREASING TENDENCY FOR CONDENSATION AND PRECIPITATION.
NEUTRAL BOUNDARIES
N
W
C
E
S
WARM MOIST AIR AND COLD DRY AIR HAVE EQUAL VELOCITIES BUT OPPOSITE DIRECTIONS.
DRY BOUNDARIES
N
W
B
E
S
COLD DRY AIR TO THE RIGHT HAS THE GREATER VELOCITIES. DRY AIR TENDS TO DIFFUSE TO THE LEFT DOWNSLOPE WITH TENDENCY FOR CLOUD DISSIPATION AND LOWERING RELATIVE HUMIDITIES.

FIG. 1

GROUP CLASSIFICATION OF VELOCITY VECTORS AT THE BOUNDARY SURFACE BETWEEN A WARM MOIST AIR MASS AND A COLDER LOWER AIR MASS.

enough convergence in the lower levels to produce additional condensation. The above outlined synoptic situation would appear as a wave on a quasi-stationary surface-front moving in the direction of flow of the air aloft when such flow is essentially parallel on both sides of the front.

Attention is next directed to the required density-velocity-slope relationships at the boundary-surface separating a lower cold air-mass from an overlying warmer air-mass. These required relationships are discussed in detail in Chapter 10 of Brunt's "Physical and dynamical meteorology," and generalizations are here made from the rules of flow outlined in that Chapter. It is found that the required velocity-discontinuities are such as to produce a cyclonic circulation across the frontal zone. When the air-masses move parallel as assumed for this discussion the higher velocities must be on the right.

The air-mass boundary-region is assumed to be a very thin layer, and across such a layer frictional shearing stresses develop. These shearing stresses will result in a transfer of momentum from the higher-velocity stream to the lower-velocity stream. This transfer of momentum is assumed to take place not gradually but sporadically by means of small eddies. Accompanying the transfer of momentum is a transfer of other air-mass properties. Special considerations are applied to an overlying warm moist air-mass and a lower colder and drier air-mass. The required velocity discontinuities are portrayed graphically in Figure 1.

It is noted that for precipitation the first class of boundaries is required. Emphasis is directed to the necessity of considering these velocity-classes in the analysis of upper-air flow. It should likewise be remembered that one of the velocity-discontinuities pictured is required at a surface-front.

In summary it can be said that when a warm moist air-mass is flowing parallel to and on the right of a cold dry air-mass, there will be a diffusion of moisture to the left upslope and a tendency for condensation and precipitation. If such a flow-pattern occurs with southwest winds to the southeast of a cold low aloft, rainfall may be quite heavy and prolonged in case the cold air is more unstable aloft than the warm air as discussed in the first part of this paper.

If the cold low aloft remains open to the north in its rear and is continually supplied by colder air, pressures at intermediate levels will continue to fall, thus tending to retard the eastward displacement of the surface-fronts. Movements of thermal centers of action aloft can be anticipated from the changes in wind-direction with height around the centers, and by use of the known relationships between temperature and pressure at upper levels.

U. S. Weather Bureau,
Washington, D. C.

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## EVIDENCE OF A SIDEREAL BAROMETRIC-PRESSURE WAVE

H. B. Maris

Humphreys [Physics of the air, 1929, p. 229] has shown that the daily tide in barometric pressure is subject to seasonal variations. This fact is well illustrated by Figure 1 which shows average daily barometric-pressure curves for each month of the year at Key West, Florida, averaged for the 14 years 1891 to 1904. Obviously, if we could neglect changes for other hours of the day and plot pressure values of the peak at 10 a.m. against sidereal hour-angle, the strong maxima of December and January as against the weak maxima of June and July would give a sidereal maxima for 10 a.m. between December and January at sidereal hour 3. However, if all of Humphrey's data for these curves are plotted against sidereal hour-angle, a maximum is obtained for sidereal hour 21, which falls exactly on a January minimum. The data of Figure 1, therefore, suggest the existence of a sidereal barometric-pressure curve which is independent of seasonal variations of the solar-pressure curve. The form of this curve would obviously be

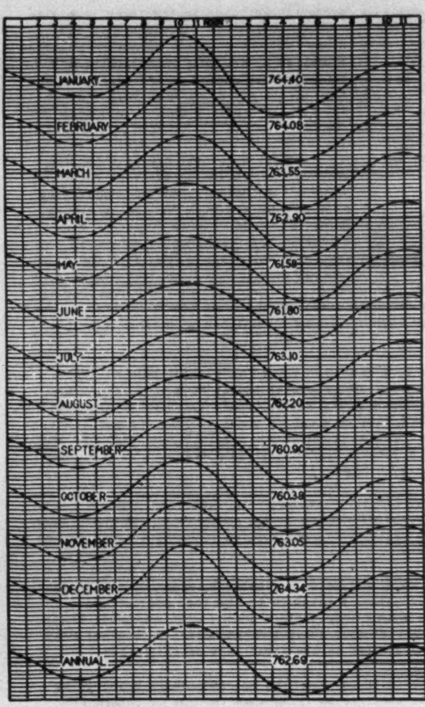

*FIG. 1—AVERAGE DAILY BAROMETRIC PRESSURE, KEY WEST, FLORIDA, 1891-1904*

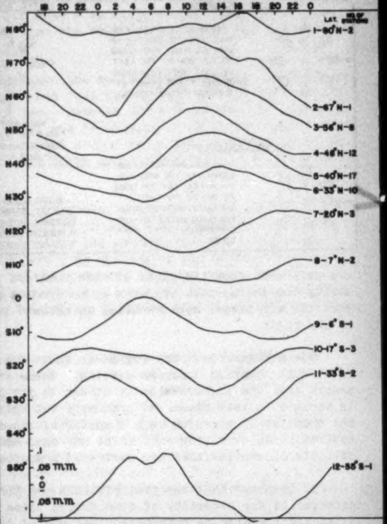

*FIG. 2—BAROMETRIC PRESSURE PLOTTED AGAINST SIDEREAL HOUR-ANGLE FOR 12 DIFFERENT LATITUDES*

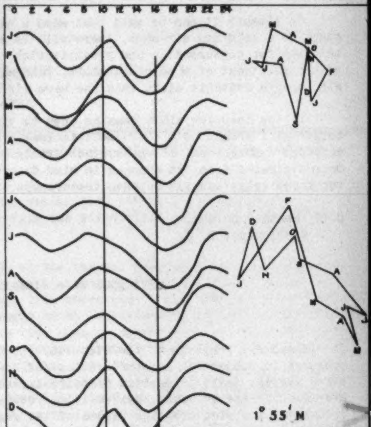

*FIG. 3—BAROMETRIC PRESSURE AND SIDEREAL HOUR-ANGLE, 1°55' NORTH*

distorted by seasonal variations of the solar curve, and in this particular case the solar curve decreases the amplitude of sidereal curve nearly 50 per cent.

Barometric pressure plotted against sidereal time for 62 stations, including 28 North American, 9 Russian, 8 English, 4 Japanese, and 3 South African stations, ranging in latitude from 80° north to 55° south, shows the sidereal-variation curves of Figure 2. Curves 3 to 6, inclusive, are quite well established by stations varying widely in longitude and altitude. It seems very improbable that additional data would change in any important detail the facts presented by these curves. They show a sidereal-pressure variation which reaches a maximum range of 0.169 mm at about latitude 60° north with the maximum pressure at sidereal hour 11, which is approximately the position of the pointer stars of the Great Dipper. These curves distinctly show a decrease in amplitude and a lag in phase-angle with decreasing latitude.

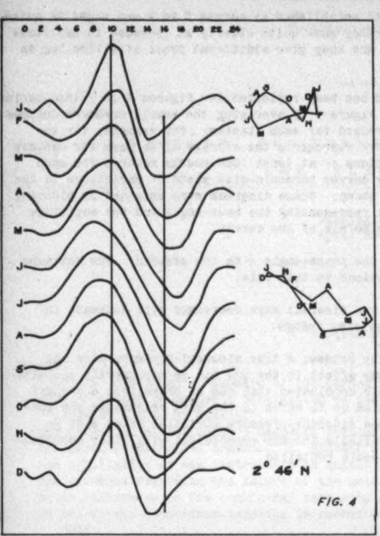

FIG. 4

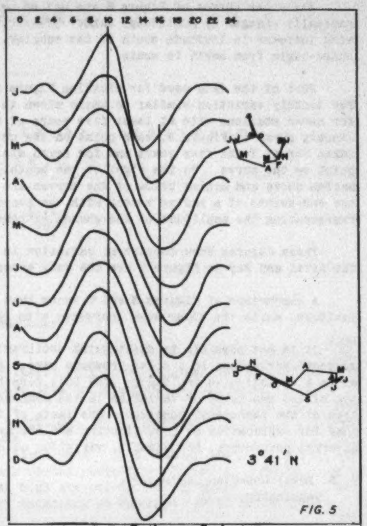

FIG. 5

FIGS. 4 & 5—BAROMETRIC PRESSURE AND SIDEREAL HOUR-ANGLE, 2°46′, AND 3°41′ NORTH

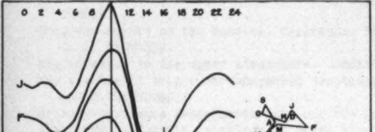

FIG. 6

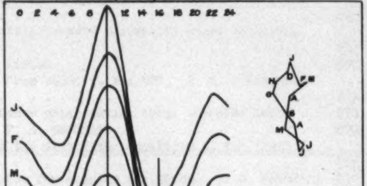

FIG. 7

FIGS. 6 & 7—BAROMETRIC PRESSURE AND SIDEREAL HOUR-ANGLE, 4°38′, AND 5°30′ NORTH

The other curves of Figure 2 are not so well established as curves 3 to 6 and might be quite radically changed by additional data. However, they show quite clearly an increase in amplitude with increase in latitude south of the equator, and they give additional proof of a time-lag in phase-angle from north to south.

Part of the data used for plotting Figure 2 has been replotted for Figures 3 to 7 into curves for monthly variation similar to those shown in Figure 1 by averaging the hourly pressure-changes for seven stations with at least five years of record for each station. For example, for the January curve of Figure 3, each point on the curve represents the average of 31 days for January taken for at least five years and for seven stations or at least 1085 hourly records for each point on the curve. To the right of the monthly curves harmonic-dial plots of variations in the maxima above and minima below of the curves are shown. These diagrams were obtained by plotting the end-points of a radius vector with the phase representing the hour-angle and the amplitude representing the amplitude of the chosen extreme points of the curves.

These Figures show consistent variation in the phase-angle with the seasons. The maximums for April and May in Figure 7 are the only exceptions to this rule.

A comparison of Figures 3 and 7 shows that the sidereal wave decreases with decrease in latitude, while the solar wave increases with the same change.

It is not possible to distinguish arbitrarily between a true sidereal-pressure wave and seasonal variations in a solar-pressure wave. Any effect in the one can be arbitrarily explained as a variation in the other. The only possible conclusion that can be drawn from a comparison of the two types of variation is the conclusion as to which is the more reasonable explanation of the phenomenon observed. The facts of the sidereal-pressure variation stand with no need for explanation or justification and are available for any association with other observed sidereal phenomenon, for example, variation of cosmic radiation.

U. S. Naval Research Laboratory,
Washington, D. C.

**AMERICAN GEOPHYSICAL UNION**

**Twentieth Annual Meeting**

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# SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

**Washington, D. C.**
**April 26-27, 1939**

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# PAPERS

## THEORY OF NEW PRIMARY STANDARD OF THE CARNEGIE INSTITUTION OF WASHINGTON

E. A. Johnson

(Abstract)

The theory of a new primary standard for measuring any component of the Earth's magnetic field is developed. The magnetometer consists of a Helmholtz-Gaugain coil which provides a standard field opposed to that component of the Earth's magnetic field which is to be measured, and a rotating coil used as a null detector. The voltage generated in the rotating coil is detected by an alternating-current amplifier. The constant of the Helmholtz-Gaugain coil is computed from the formulas developed by C. Snow from the mutual inductance between two concentric cylinders. Corrections are computed for the fact that the Helmholtz-Gaugain coils are helices, for the axial components of current, for the effect of the lead-in wires, and for non-uniformities in winding. The finite size of the detector is not a limitation on the accuracy since it is taken into account in the computation. Consequently, the accuracy of the coil-constant of the new standard depends only upon constructional accuracy. Inhomogeneity in the field of the Helmholtz-Gaugain coil necessitates the use of small correction-terms to the voltage of fundamental frequency generated in the detector and produces odd harmonics of the fundamental frequency in the detector. The errors in orientating the Helmholtz-Gaugain coil are also examined. The limiting sensitivity of the detector is calculated from the thermal agitation of electricity in the coil of the detector.

The complete paper is published in the Journal of Terrestrial Magnetism and Atmospheric Electricity, v. 44, pp. 29-42, 1939.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

## SECULAR CHANGE IN MAGNETIC DECLINATION AS DEDUCED FROM POLARIZED VARVE-SEDIMENTS

E. A. Johnson and A. G. McNish

(Abstract)

The method reported at the annual meeting in 1938 of the Section of Terrestrial Magnetism and Electricity for measuring the weak polarization of sedimentary deposits has been applied in an investigation of the polarization of the varved Pleistocene clays left at the retreat of the last glaciation in New England. The chronology of these varves has been investigated by Antevs so that several thousands of years of dated deposits are available. The actual chronology is not yet connected with our own chronology, but begins at an arbitrary varve selected by Antevs. Using Antevs' dating it has been possible in a preliminary investigation to follow the changes in the direction of polarization in varves deposited at West Hartford, Connecticut, for about 500 consecutive years, and for an additional 200 years in varves of another series at New Haven, Connecticut.

The direction of polarization in the varves is interpreted as a direct measure of the direction of the magnetic compass at the time the deposits were laid down. From the results of the measurements it can be concluded that the rate of secular variation in this prehistoric period did not differ appreciably from the rates observed in historic times. Furthermore, the direction of the polarization is approximately to the north, and there is no indication that the direction of the Earth's field was reversed during this period.

The absolute accuracy of the measurements depends upon the accumulative errors originating during collection of the clay, preparation of cubical specimens, measurement of the direction of polarization, and distortions occurring in the varves themselves. The errors in the data from these two locations is estimated at ±3° for 20-year averages. This error will probably be considerably reduced in succeeding collections and ought not to exceed ±1°. Tentative plans have been made to extend the measurements to cover the entire series of varves, thus making available data for the study of secular variation for thousands of years.

Department of Terrestrial Magnetism, Carnegie Institution of Washington,
Washington, D. C.

## THE POTENTIAL OF THE EARTH'S MAGNETIC SECULAR VARIATION

E. H. Vestine

(Abstract)

Data on secular variation given by Fisk for the epoch 1920-1925 are described. From these data are obtained new isoporic charts showing the geographical distribution of the north and east components of the variation. Tentative measures are applied to test the accuracy of the data. In making these tests it is assumed that the secular variation of the Earth's non-potential field, if the latter exists, should be very small or zero, in the case of accurate magnetic data. Line-integrals were evaluated for the horizontal component of secular change taken along parallels of latitude and meridians of longitude, and also around tesseral areas. The results indicated that these line-integrals would vanish if the error in the data averaged along the path of integration were less than about 20 per cent of the observed secular change as given by Fisk, except in south polar regions where the average error along parallels of latitude is estimated to exceed 100 per cent. The values of the line-integrals were found to vary in a systematic way over the Earth, thus strongly suggesting the presence of important systematic as well as accidental errors in world-wide maps of the Earth's field.

An approximate derivation is obtained of a world-wide representation of secular variation by an equivalent isoporic magnetic shell just beneath the Earth's surface. In the Atlantic Ocean the intensity of magnetization of the shell attains a maximum value of 70,000 CGS, a value large to be ascribed to magnetization acquired or lost through annual radial shifts in the position of the Curie-point isothermal surface for the thermoremanence of magnetite.

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Washington, D. C.

## THE EARTH'S QUADRUPOLE MOMENTS

H. Herbert Howe

(1) General--In a simply-connected region in which there are no electric currents and no magnetic materials, a magnetic field may be expressed as the gradient (more commonly negative gradient) of a single-valued potential V. This potential satisfies Laplace's equation

$$\nabla \cdot \nabla V = 0 \tag{1}$$

where $\nabla$ (pronounced "del") is the vector differential operator [see 1 of "References" at end of paper] for the gradient, its equation being

$$\nabla = i\partial/\partial x + j\partial/\partial y + k\partial/\partial z \tag{2}$$

It is well known that the potential can be expressed by an infinite series of "spherical harmonics." In terms of ordinary polar coordinates, the spherical harmonics are usually classified by the degree of r. There is one spherical harmonic of each of the degrees 0 and -1, namely, $r^0$ and $r^{-1}$ (times, in every case, any arbitrary constant). There are three each of degree +1 and -2, namely, r and $r^{-2}$, respectively, multiplied by cos θ, sin θ cos φ, or sin θ sin φ, where θ is the polar angle and φ is the longitudinal angle. Similarly, there are five spherical harmonics of degree +2 or -3, seven of degree +3 or -4, and so on.

In the case of the Earth, if the harmonics are expressed with the center of the Earth as origin, those with positive powers of r increase indefinitely as the distance from the center increases; consequently, there must be a region above the Earth in which they cease to represent the field, that is, the magnetic material or electric currents (in this case, obviously the latter) responsible for this portion of the potential must lie above the Earth's surface. On the other hand, the portion with negative powers of r increases indefinitely as the center of the Earth is approached; hence, these portions must be due to currents or magnetic materials within the Earth.

The spherical harmonic of degree 0 is merely an irrelevant additive constant. That of degree -1 may be ascribed to a pole at the origin; hence, it vanishes in the case of magnetism. The harmonic of degree -2, which is associated with the greater part of the Earth's field, may be represented by a dipole at the origin. The harmonic of degree -3 may be ascribed to quadrupoles at the origin, that of degree -4 to octupoles, etc.

The remainder of this paper will deal with the physical picture of a quadrupole, the derivation of its potential and field, the discussion of the representation of spherical harmonics of degree -3 by quadrupoles, and finally the determination of the orientations and magnitudes of the Earth's quadrupole moments.

(2) Pole--Let p represent the pole-strength of a point-pole at O. p is positive for a north-seeking pole. Let $V_p$ be the potential at some specified point P; $\mathbf{F}$, the field at P; $\mathbf{R}$, the position-vector from O to P; and r, the magnitude of $\mathbf{R}$. Then it is known that

$$V_p = p/r \tag{3}$$

$$\mathbf{F} = -\nabla V_p = -\nabla(p/r) = -p\nabla(1/r) \tag{4}$$

since p is a constant in the differentiation. The differentiation in (4) will be carried out later.

(3) Dipole--Next, consider the combined field of this point-pole and another point-pole of pole strength -p, located at O'. The position-vector of O' referred to O is to be $\mathbf{L}$. There are two scalars involved in the pair of poles, namely, the magnitude of $\mathbf{L}$ and the value of p. The so-called dipole potential or field may be obtained in either of two ways: (1) Let $\mathbf{L}$ become zero and p become infinite, in such a way that the product $\mathbf{L}p$ remains constant--there is then just one magnitude involved, namely, that of the product; (2) express the potential in powers of 1/r, and then retain only the lowest power of 1/r. It may be readily shown that the two concepts give the same result. (It is to be remembered that two finite poles with finite separation do not constitute a dipole; they have also, in general, all higher spherical harmonics.)

To evaluate the potential of a dipole, return to the original pole. V is a function of the position-vector $\mathbf{R}$, and may be written $V = f(\mathbf{R})$. Since the space is assumed isotropic and homogeneous, the potential at a given point is determined by the vector from the pole to the given point. That is, the potential at position $\mathbf{R}$ due to a pole -p at position $\mathbf{L}$ is equal to the potential at position $\mathbf{R}-\mathbf{L}$ due to a pole -p at O, since in each case the position-vector from the pole to the desired point is $\mathbf{R}-\mathbf{L}$; that is, the potential of the second pole at point P is $-f(\mathbf{R}-\mathbf{L})$, and the potential of the two poles is

$$V = f(\mathbf{R}) - f(\mathbf{R}-\mathbf{L}) \tag{5}$$

Now it is known that for a small change of position the lowest-order term in the change of f may be obtained by an equation similar to the first two terms of a Taylor's series, namely

$$f(\mathbf{R}-\mathbf{L}) \doteq f(\mathbf{R}) - \mathbf{L}\cdot\nabla f(\mathbf{R}) \tag{6}$$

Therefore, the potential of the dipole is

$$\begin{aligned} V_d &= f(\mathbf{R}) - f(\mathbf{R}) + \mathbf{L}\cdot\nabla f(\mathbf{R}) \\ &= \mathbf{L}\cdot\nabla(\text{potential of pole}) = p\mathbf{L}\cdot\nabla(1/r) \end{aligned} \tag{7}$$

or, replacing $p\mathbf{L}$ by $-\mathbf{M}$, where $\mathbf{M}$ is the magnetic moment of the dipole, reckoned as a vector directed from the negative pole toward the positive one,

$$V_d = -\mathbf{M}\cdot\nabla(1/r) \tag{8}$$

and the field of the dipole is

$$\begin{aligned} \mathbf{F} &= -\nabla V_d = \nabla[\mathbf{M}\cdot\nabla(1/r)] = \nabla[\nabla(1/r)\cdot\mathbf{M}] \\ &= (\nabla\nabla r^{-1})\cdot\mathbf{M} = \mathbf{M}\cdot(\nabla\nabla r^{-1}) \end{aligned} \tag{9}$$

since $\mathbf{M}$ is independent of the differentiation and $\nabla\nabla r^{-1}$ is a symmetric tensor.

(4) Quadrupole--Thus a dipole may be obtained from a pole by adding another pole of opposite sign, displaced infinitesimally from the first and of such magnitude that the product of the pole-strength and displacement is constant, as the displacement approaches zero. Similarly, a

quadrupole may be obtained from a dipole by adding another dipole of opposite sign, displaced infinitesimally from the first and of such magnitude that the product of the dipole moment and the displacement is constant, as the displacement approaches zero. Or, analogous to the other definition of a dipole, we may consider four finite poles such that the net pole and net dipole cancel, and consider only the lowest remaining power of 1/r.

In the case of a dipole, the isotropy of space makes all dipoles intrinsically alike, differing only in strength and in orientation in space. In the case of a quadrupole, there are different varieties, according to the relation of the direction of the initial dipole moment and the direction of the displacement. This is illustrated in Figure 1. Because of isotropy, however, we do not get different types of quadrupoles by considering other planes; the type is defined by the angle $\theta$ between the vectors $\mathbf{N}$ and $\mathbf{M}$.

(5) Derivation of formulas--Let $\mathbf{N}$ be the vector from the center of the second dipole to the center of the first. Then, applying the same method as was used in the case of a dipole, we have

$$V_q = -\mathbf{N}.\nabla V_d = \mathbf{N}\,.\,(\nabla\nabla r^{-1}).\mathbf{M} = (\mathbf{NM}) : (\nabla\nabla r^{-1}) \tag{10}$$

where : signifies the scalar product of the two second-order tensors. The tensor $\mathbf{NM}$ will be called the "quadrupole moment." The field of this quadrupole, again making use of the fact that $\mathbf{N}$ and $\mathbf{M}$ are independent in the differentiation, is

$$F_q = -(\mathbf{NM}) : (\nabla\nabla\nabla r^{-1}) \tag{11}$$

Since the last tensor in (10) or (11) is the same for any quadrupole, we can study the classification and summation of quadrupoles by studying chiefly the first tensor, the quadrupole moment.

(6) Summation of quadrupoles--The potential or field due to any number of quadrupoles may be obtained by summing the potentials or fields for the quadrupoles. That is, we sum the quadrupole moments, represented in (10) or (11) by $\mathbf{NM}$. Since any arbitrary second-order tensor may be obtained by summing dyads of this form, any second-order tensor may represent a quadrupole moment or the sum of quadrupole moments, just as any vector may represent a dipole moment. It may be shown that any spherical harmonic of degree -3 may be obtained as the scalar product of some second-order tensor and the tensor $\nabla\nabla r^{-1}$; that is, it may be represented as due to the sum of quadrupoles. We shall consider later the question of the minimum number of quadrupoles in such a representation.

(7) Classification of second-order tensors--The general second-order tensor has nine independent components. It may be expressed as the sum of three tensors of different transformation-properties, as follows: (1) A totally-symmetric tensor (one independent component)--it is a scalar times the identity-tensor; (2) an anti-symmetric tensor (three independent components); (3) an "anisotropic tensor" (five independent components)--it is symmetric, but the diagonal sum is zero.

It may be readily shown that the scalar product of a tensor of one type with a tensor of a different type is zero. Now $\nabla\nabla r^{-1}$ is symmetric; further, its diagonal sum is zero, since this is obtained by contracting it, and $\nabla\cdot\nabla r^{-1}$ is known to be zero, since $r^{-1}$ is a solution of Laplace's equation. Therefore, $\nabla\nabla r^{-1}$ is anisotropic.

Hence we may, if convenient, add any totally-symmetric or anti-symmetric tensor we please to the quadrupole moment $\mathbf{NM}$ without altering the potential or field. That is, only the anisotropic part is significant. (There are five independent components to the general anisotropic tensor, which checks the fact that there are five independent spherical harmonics of degree -3.)

(8) Types of quadrupoles--Since a quadrupole is defined by its quadrupole moment, it will be seen that, for example, one of the type shown in Figure 1(a) plus one of type 1(c) gives one of type 1(b), since the dipole moments are the same in all three cases, so that we are concerned only with vector addition of the displacements. However, types 1(a) and 1(c) are actually linearly independent. Types 1(a) and 1(e) differ only in sign; the initial dipole is the same in the two cases, and the direction of displacement is of opposite sign.

The two quadrupoles in Figure 2 are equivalent; the direction of the initial dipole is reversed, but the direction of the displacement is also reversed. If we regard the quadrupole as composed of four poles rather than of two dipoles, it is obvious that they are the same.

The two essentially different types of quadrupoles shown in Figures 1(a) and 1(c) will be

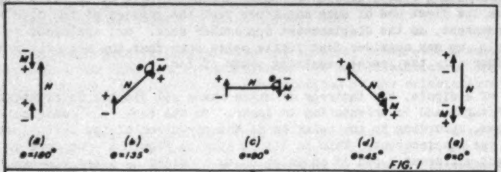

FIG. 1

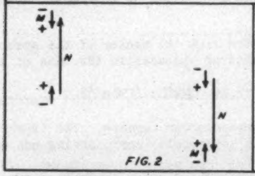

FIG. 2

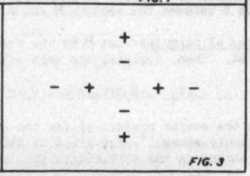

FIG. 3

*FIG. 1—SHOWING THAT ALL QUADRUPOLES ARE NOT OF SAME NATURE; LONG ARROW IS DISPLACEMENT OF FIRST DIPOLE WITH RESPECT TO SECOND; SHORT ARROWS ARE MAGNETIC MOMENTS OF THE TWO DIPOLES [ONLY TYPES (a) AND (c) ARE LINEARLY INDEPENDENT]*

*FIG. 2—SHOWING THAT CHANGING SIGN OF INITIAL DIPOLE AND OF DISPLACEMENT LEAVES QUADRUPOLE UNCHANGED*

*FIG. 3—ILLUSTRATING RELATION BETWEEN LINEAR AND PLANAR QUADRUPOLES*

called, respectively, linear and planar quadrupoles. By comparing Figures 1(a) and 1(e) it will be seen that a sign may be attributed to a linear quadrupole, depending upon whether the positive or negative poles are outside. Type 1(e) will be called a positive quadrupole and type 1(a) a negative quadrupole.

If $i$, $j$, and $k$ be unit orthogonal vectors, a positive quadrupole has a tensor of the type $qii$, a negative quadrupole has one of the type $-qii$, and a planar quadrupole has one of the type $qij$ or $-qij$--$q$ in each case being positive.

(9) Relation of planar and linear quadrupoles--Although planar and linear quadrupoles are unrelated so long as we consider dipoles with a given orientation, they are related when we consider different orientations. Consider (Fig. 3) two linear quadrupoles of equal magnitude but opposite sign, directed at right-angles. The four inner poles constitute a planar quadrupole, whose principal directions are inclined 45° to those of the linear quadrupoles. The four outer poles are also a quadrupole; the sign is opposite to that of the inner quadrupole, but, since the distances are greater, the magnitude is greater. We may add the two together (since only the pole-strength times the square of the distance is significant) and obtain a resultant planar quadrupole.

Analytically, this is shown as follows: The quadrupole moments are $qii$ and $-qjj$. If we use other axes obtained from the first by rotating through 45°, the unit-vectors in this system are

$$i' = (i + j)/\sqrt{2} \qquad j' = (i - j)/\sqrt{2} \tag{12}$$

and we find that

$$qii - qjj = q\,(i'j' + j'i') \tag{13}$$

(10) Three equal perpendicular linear quadrupoles--Next consider three linear quadrupoles, equal in magnitude, directed in three mutually-perpendicular directions. The quadrupole moments are $qii$, $qjj$, and $qkk$. The sum of them is simply

$$qii + qjj + qkk = qI \tag{14}$$

where $I$ is the identity-tensor. But this is a totally-symmetric tensor; hence, by the principal of section (7) the resultant potential of the three quadrupoles is just zero.

(11) Principal axes--We now consider the simplest method of expressing any arbitrary spherical harmonics of degree -3 as due to a number of quadrupoles. We may always obtain a symmetric tensor T by subtracting off the anti-symmetric part, since by section (7) it is irrelevant. (For example, a planar quadrupole $q\mathrm{ij}$ is equal to the planar quadrupole $q\mathrm{ji}$, and both are equal to the symmetric tensor $(q/2)(\mathrm{ij}+\mathrm{ji})$.) For any symmetric tensor of the second order there exist three mutually perpendicular directions (unit-vectors along them being designated by $\mathrm{i}$, $\mathrm{j}$, and $\mathrm{k}$) such that

$$T = a\mathrm{ii} + b\mathrm{jj} + c\mathrm{kk} \tag{15}$$

a, b, and c being scalars. Therefore, if a magnetic field be expressed in spherical harmonics, there exist three mutually perpendicular directions such that the harmonics of degree -3 may be represented by linear quadrupoles having those directions. These directions may be called the principal axes of the quadrupole potential.

However, by section (10), we may add any amount we please to a, b, and c, provided the same amount be added to each. Thus, we get alternative representations of the type $T = a'\mathrm{ii} + b'\mathrm{jj}$. Further, we may add such an amount to a, b, and c that two of them are equal but of opposite sign; then they represent together a planar quadrupole. These different representations are illustrated later in the case of the Earth.

(12) Evaluation of the derivatives--We shall now evaluate the derivatives used in formulas (4) to (11). The operator $\nabla$ operates upon a function of a variable in a manner analogous to an ordinary differential operator; that is

$$\nabla f(r) = [df(r)/dr]\nabla r \tag{16}$$

It may be readily shown in various ways [for example, using formula (2)] that

$$\nabla r = \mathrm{R}/r; \quad \nabla \mathrm{R} = \mathrm{I} \tag{17}$$

$\mathrm{I}$ being the identity-tensor. Therefore,

$$\nabla r^{-1} = -r^{-3}\mathrm{R} \tag{18}$$

$$\nabla\nabla r^{-1} = -(\nabla r^{-3})\mathrm{R} - r^{-3}(\nabla \mathrm{R}) = 3r^{-5}\mathrm{RR} - r^{-3}\mathrm{I} \tag{19}$$

Differentiating a third time, remembering that the operator must operate on each variable and that the proper order must be maintained for the vectors in each term, we have

$$\nabla\nabla\nabla r^{-1} = -15r^{-7}\mathrm{RRR} + 3r^{-5}(\mathrm{IR} + \mathrm{RI} + \mathrm{JRJ}) \tag{20}$$

the tensor $\mathrm{JRJ}$ being similar to $\mathrm{IR}$ except that the identity-tensor is split by the $\mathrm{R}$, that is,

$$\mathrm{JRJ} = \mathrm{iRi} + \mathrm{jRj} + \mathrm{kRk} \tag{21}$$

(13) Potential of a quadrupole in polar coordinates--Consider a positive linear quadrupole, whose moment is $q\mathrm{ii}$. From (10) and (19)

$$V_q = qr^{-3}(3\cos^2\theta - 1) \tag{22}$$

$\theta$ being the angle between $\mathrm{R}$ and $\mathrm{i}$.

Next, consider a planar quadrupole, of moment $q\mathrm{jk}$. If $\varphi$ is the longitudinal angle, we get

$$V_q = qr^{-3}(3\sin^2\theta \cos\varphi \sin\varphi) \tag{23}$$

(14) Quadrupole moments of the Earth--As an illustration of the theory, let us consider the quadrupole moments of the Earth. Dyson and Furner [2] give spherical harmonics for this case. Considering only the values which they give for the harmonic coefficients as derived from the north and east intensities, their formula for the spherical harmonics of degree -3 becomes

$$(a/r)^3 [(1/2\cos 2\theta + 1/6)(13.3) - 1/2\sin 2\theta(-51.8\cos\varphi + 21.5\sin\varphi)$$
$$+ (1/2\cos 2\theta - 1/2)(12.5\cos 2\varphi + 7.3\sin 2\varphi)] \tag{24}$$

in which a is the radius of the Earth, r is the distance from the center, reckoned with a equals unity, $\varphi$ is the longitude east from Greenwich, $\theta$ is the north-polar distance, and the magnetic intensities are to be reckoned in unrationalized mks units [3]. (1 mks unrationalized unit = 100γ or 0.001 cgs electromagnetic unit.)

The determination of the principal axes is essentially a problem in rotating the general ellipsoid to its principal axes. It is found that the three principal axes and the corresponding quadrupole moments are:

| Axis number | 1 | 2 | 3 |
|---|---|---|---|
| Latitude | 31° 34′.5 N | 24° 25′.3 N | 48° 09′.1 S |
| Longitude | 0° 57′.6 E | 105° 14′.3 W | 45° 42′.3 W |
| Quadrupole moment | -11.331 | 0.000 | +10.313 |
| Or (form 2) | -10.822 | +0.509 | +10.822 |
| Or (form 3) | 0.000 | +11.331 | +21.644 |
| Or (form 4) | -21.644 | -10.313 | 0.000 |
| Or (form 5) | - 5.666 | +5.665 | +15.978 |

These alternative forms arise because of the possibility of adding any desired amount to all three quadrupole moments. Forms 1, 3, and 4 may be used with the determination of only two arcs. In form 2, nearly all of the result is expressed as a planar quadrupole, with a small linear quadrupole perpendicular to its plane. In form 5, the principal effect is a linear quadrupole, with a comparatively small planar quadrupole perpendicular to it.

It is to be understood that the number of figures given is greater than is physically significant. It was intended that the data should give the same field as those of Dyson and Furner, within about 1γ.

(15) Summary--It is not to be understood that the use of principal quadrupole moments is more convenient than the use of spherical harmonics in case exact computations are to be made. They are, however, useful as giving a picture of the potential; or for rough computations, in which the arcs may be scaled from a globe.

## References

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[2] F. Dyson and H. Furner, "The Earth's magnetic potential," Month. Not. R. Astr. Soc., Geophys. Supp. 1, pp. 76-88, 1923.

[3] A. E. Kennelly, "I.E.C. adopts mks system of units," Elect. Eng., Dec., 1935; "Magnetic formulae expressed in the mks system of units," Proc. Amer. Phil. Soc., v. 76, No. 3, 1936.

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## THE APPLICATION OF NEW INSTRUMENTS TO MAGNETIC FIELD-WORK

H. E. McComb and J. W. Joyce

Introduction--In past years, magnetic land-surveys have consisted essentially of the determination of the absolute values of magnetic declination (D), dip (I), and intensity (H, Z, or F), at marked or unmarked stations. In later years, it has usually been the practice to measure horizontal intensity (H), rather than total intensity (F). Standard instruments for this work consist of field-magnetometers for the measurement of declination and intensity, and either earth-inductors or dip-circles for dip.

In observing declination, it is necessary first to determine by astronomical observations a true azimuth or bearing to some object that can be used as a mark of reference. An adequate number of pointings of a suspended magnet are then made, and from their mean value, the true bearing of the reference-mark, and the instrumental correction, declination is determined. If a magnetometer is used, the magnet is suspended by either a silk or metallic fiber, so that when the magnet is in the meridian, there is no torsion in the suspension. Another instrument used to measure declination, where great accuracy is not required, is known as a compass-declinometer. It consists essentially of a compass-needle supported on a steel pivot bearing on a jewel. Peep-sights are used to line the instrument on the mark.

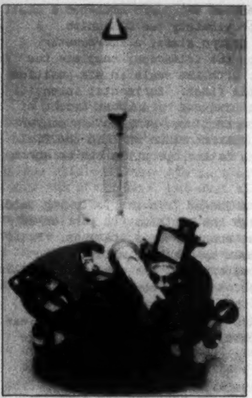

FIG. 1—QUARTZ HORIZONTAL MAGNETOMETER (QHM)

In the determination of horizontal intensity with a magnetometer, two series of observations are required. First, the period of oscillation of a suspended magnet is determined; second, the distortion on the horizontal component of the Earth's field produced by this same magnet at various distances from an indicator magnet is measured. From these two series of observations H is derived.

These older methods, especially for the determination of H and I, are time-consuming and involve rather special techniques in observing. In the case of H, over an hour is required for an observation, and if for any reason the observer is interrupted during the course of the observation, the latter is frequently rendered worthless.

With the development of newer and better magnet-steels, so-called permanent magnets are now being produced whose magnetic moments remain far more constant with time and usage than formerly. Advantage has been taken of this fact to produce several new instruments which greatly reduce the time necessary for making magnetic field-observations, and, while exacting care is essential in the operation of these instruments, the basic technique has been greatly simplified. It should be stated in passing that early measurements of the relative values of horizontal intensity at various stations were made by comparing the times of oscillation of the same magnet at the different stations, assuming the moment of the magnet to remain constant. In the present methods, relative values are determined by deflections instead.

QHM--The first of two new instruments to be described in this paper is the quartz horizontal magnetometer, or QHM, developed by Dr. D. la Cour of the Danish Meteorological Institute at Copenhagen. The successful operation of the QHM depends on the constancy with time of the torsion-constant of a quartz fiber and the magnetic moment of a small bar-magnet. The instrument is

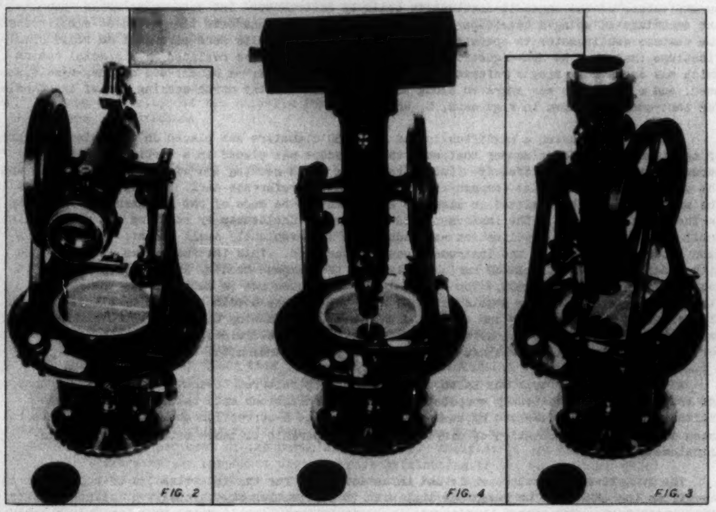

FIG. 2

FIG. 4

FIG. 3

FIGS. 2,3,& 4—TRANSIT-MAGNETOMETER (FIGURE 4 SHOWS DEFLECTOR-MAGNET HOLDER USED TO MEASURE HORIZONTAL INTENSITY; FIGURE 3 SHOWS NORMAL POSITION FOR READING MAGNET AND FOR READING MICROSCOPE) shown in Figure 1. It consists of a quartz fiber to the lower end of which are attached a small plane mirror and a bar-magnet, the latter having a moment of approximately two CGS units. A telescope with a Gaussian eyepiece containing a scale etched on ground glass, a thermometer, a horizontal circle, the instrument-cover, and a counterbalance for the telescope, complete the assembly. The instrument is adjusted by the manufacturer until, with the scale in mid-position and the magnet in the meridian, there is negligible torsion in the fiber. Horizontal intensity is then measured by observing the deflection of the small magnet produced by a known amount of torsion in the quartz fiber, taking due account of temperature-corrections. Angles are measured on the horizontal circle, and it is possible to make a complete determination of H in the field in from six to eight minutes after the instrument is set up. The latter operation can be accomplished in less than five minutes by an experienced observer.

How well these instruments maintain their calibration may be judged from the following data: In March, 1939, the writers made a three-weeks' field-trip through the southeastern portion of the country, traveling some 3100 miles by truck, and observing at about a dozen stations. Prior to leaving on the trip, three QHM's were standardized at Cheltenham by making simultaneous observations with the standard CIW sine-galvanometer at that Observatory. At the conclusion of the trip, the three instruments were restandardized, and the differences in the corrections, based on preliminary computations, were found to be considerably less than the probable error (±0.3γ) in the case of two of them, and 1.1±0.3γ for the third. Two years ago, a similar instrument was compared at Cheltenham, shipped to Sitka, Alaska, and then returned to Cheltenham. The change in the instrumental correction was of the order of one gamma.

With proper handling, the QHM is far superior to the magnetometer for field-work, both from the standpoint of time and simplicity of operation. The results appear to be of one order of magnitude greater accuracy, and, in addition, the instrument is well suited to the determination of diurnal variation. It must be handled with care to preserve the quartz fiber, and should be restandardized at intervals of not more than two to three months--oftener if convenient.

*The transit-magnetometer*--One of the greatest objections to the compass-declinometer has been the use of peep-sights for making readings on the mark. With the improvement in instrument-construction, it was felt that if a standard transit equipped with a 3.5-inch or 4-inch compass could be made entirely of non-magnetic materials except for the compass-needle and pivot, accurate values of the magnetic declination could be determined. The instrument would then have the advantage of using a telescope for mark-readings and at the same time would be simpler than the compass-declinometer to operate. Accordingly, such transits were purchased on rigid specifications that they be non-magnetic. The usual compass-limb was replaced by a special one on which was engraved a single reference-line at the north point. A square-end compass-needle was used, and a fine line was engraved along the center line at the north-seeking end of the needle. The instrument is shown in Figures 2, 3, and 4.

A microscope having a magnification of about 30 diameters was placed on the telescope-barrel of the transit in such a manner that, when the telescope was placed in a vertical position as shown in Figure 3, the microscope-field covered the north-seeking end of the compass-needle and the adjacent portion of the compass-limb containing the reference-mark. Parallel cross-hairs in the microscope-field permitted an accurate adjustment to be made of the alignment of the marks on the needle and limb. The instrument was adjusted at Cheltenham by rotating the compass-limb until the correction to declination was reduced to a conveniently small amount. The limb was then securely clamped and the instrument was standardized. This instrument was also equipped with a deflector-magnet, placed horizontally over the compass-needle, and arranged so that it could be rotated through 180°. The magnet in its insulated box is shown on the instrument in Figure 4. By measuring the double deflection of the compass-needle produced by placing the deflector first with its north end east, and then west, and knowing the temperature and temperature-coefficient of the deflector, horizontal intensity can be determined. The value of the constant for a given instrument is obtained experimentally by standardization-observations.

A transit of this type was taken on the field-trip referred to above. During the course of the trip, based on preliminary computations of standardizations made before and after, the declination-correction changed by less than 0!1, and the H-correction about 4γ. The ranges between individual determination of corrections are comparable to those obtained for a field-magnetometer.

The transit-magnetometer, while not as satisfactory for the determination of horizontal intensity as the QHM, has the advantage that with it declination may be observed. Although it is a pivot-instrument, with proper handling it is believed that it will prove to be useful in field-work.

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# NEW EVIDENCE REGARDING THE NATURE OF THE PRIMARY COSMIC RADIATION

Thomas H. Johnson

(Abstract)

It is generally recognized that the cosmic radiation in the atmosphere consists of two components, the hard component and the soft. The interpretation of the soft component as the product of primary electrons which multiply in passing through the atmosphere according to the well-known quantum mechanical principles is completely satisfactory but the hard component presents some serious difficulties. Its particles, the mesotrons, are undoubtedly produced as secondaries within the atmosphere, but what kind of primary particles produce the mesotrons has been until now an unsolved problem. If those particles were the electrons of the soft component, the soft component like the hard component would have to possess the distinguishing characteristic of its positive primaries of being asymmetrically distributed in angle in the regions near the equator. On the other hand, if the two components are independent, the soft component might show no asymmetry despite the fact that the hard component is known to be so strongly asymmetric that it must have been produced entirely by positive primaries.

Dr. J. G. Barry and the writer have investigated, in a new attack on this problem, the east-west asymmetry of the soft component near the equator by sending triple coincidence counters into the stratosphere with free balloons. The data were transmitted to a ground station by short-wave radio signals. Direct comparisons between the eastern and western intensities were made on flights in which the orientation of the instrument was determined by means of a photocell actuated by light from the Sun. On other flights we have studied the fluctuations which would be introduced into the counting rates by the rotation of the balloon if the radiation were non-uniform in azimuth. The results show that the asymmetry is less than about seven per cent, a value far below what would have been expected if all of the primary radiation were positive. Analysis shows that less than ten per cent of the intensity at a depth of one meter of water can be attributed to unbalanced positives. Contrasting this result with that found from the asymmetry at sea-level that the mesotrons of the hard component are produced entirely by positives, one is led to the conclusion that the hard and the soft components are separate and that the hard component must be produced by positive rays which are neither electrons nor mesotrons and must therefore be protons or some other more massive positive particle. An argument based upon the potential equilibrium and the neutrality of space can be made to show how proton rays of high energy would be expected to occur.

The complete paper is to be published in Physical Review.

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# SOLAR INFLUENCES ON THE COSMIC-RAY INTENSITY AT HIGH ELEVATIONS

S. A. Korff

(Abstract)

In order to ascertain whether any component of the cosmic radiation at high elevations might be of solar origin, a series of balloon-flights was made. The intensity of the radiation was measured by single Geiger counters, the impulses being scaled down about 50:1 and then automatically transmitted to the receiving station on the ground by short-wave radio. Flights were made both during the day and during the night. An arrangement was employed to cause the flight to level off at a high elevation. On one flight, while the instrument was floating at 66,000 feet, an intense solar flare took place. No change in intensity of the cosmic radiation was observed, up to levels of about half a meter of water-equivalent below the top of the atmosphere attained on these flights, either between day and night, or coincident with the flare, as large as the experimental error of about two per cent. The observations lead to the conclusion that there is no penetrating radiation originating in the Sun, which is capable of penetrating as much as five per cent of the Earth's atmosphere. Analysis of the negative result showed that if there were any component of gamma rays originating in the Sun, either under normal circumstances or at the time of a flare, these must have a mass absorption-coefficient of between 0.1 and 25 per gram. Any radiation in the form of charged particles emanating from the Sun must lie in the energy-range below $10^9$ electron-volts, an energy too low to be able to penetrate the Earth's magnetic field in the latitudes (50° north geomagnetic) where the observations were made.

The complete paper is to be published in the Journal of the Franklin Institute.

Bartol Research Foundation of the Franklin Institute,
Swarthmore, Pennsylvania

## ON THE 27-DAY RECURRENCE-TENDENCY IN COSMIC-RAY INTENSITY AT HUANCAYO, PERU

S. E. Forbush

### (Abstract)

The 27-day recurrence-tendency in cosmic-ray intensity at Huancayo, Peru, is investigated by means of the harmonic dial [see 1 of "References" at end of paper] for 27-day waves derived from 34 intervals of 27 days, beginning June 13, 1936. While tests for the significance of the average of the 34 vectors in the harmonic dial indicate that their directions (or the phases of the thirty-four 27-day waves) are not random, these data alone are inadequate to demonstrate whether the 27-day wave is persistent or quasi-persistent. However, in the 27-day harmonic dial for the American magnetic character-figure, the vector derived from each interval of 27 days is found, by a statistical test suggested by J. Bartels [2], to have a definite tendency to be directed oppositely to that of the vector, for the same interval, in the harmonic dial for the 27-day wave in cosmic-ray intensity. In addition, some correlation exists between the magnitudes of the two vectors for corresponding intervals. When this is also taken into account, the correspondence between the 27-day waves in cosmic-ray intensity and American character-figure (with phase of latter changed 180°) must be regarded as significant.

This indicates that the cosmic-ray intensity is on the average lower during periods of increased magnetic activity (higher character-figure), which is consistent with the magnetic-storm effect in cosmic-ray intensity [3].

In addition, the correspondence between the 27-day waves in cosmic-ray intensity and magnetic character-figure implies that the former is quasi-persistent--since J. Bartels [1] has beautifully demonstrated the quasi-persistent nature of the latter. This association between magnetic activity and cosmic-ray intensity suggests that the mechanism responsible for the changes in cosmic-ray intensity is the same as that for the magnetic-storm effect [3] and for the world-wide changes [4].

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[2] J. Bartels, unpublished lecture before Phil. Soc. Washington.
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[4] S. E. Forbush, Phys. Rev., v. 54, 975-988, 1938.

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## THE DETERMINATION OF AURORAL ACTIVITY BY A PHOTOMETRIC METHOD

L. B. Snoddy and V. C. Snoddy

In the majority of records of auroral activity the total intensity has been estimated visually and the results expressed in international coefficients [see 1 of "References" at end of paper]. This is a useful method but is liable to inaccuracies due to individual differences in observers and to the difficulty of forming any precise estimate of intensity-variations when these are accompanied by changes in color and by a movement of the luminous regions.

In a few cases objective records of activity have been made. The French Polar-Year Party at Scoresby Sound used an electrical device for measuring intensity [2]. It appeared to be very satisfactory, even detecting auroras during foggy weather. The records show that the luminous intensity may vary in the ratio 1:1000. The method does not seem, however, to be in general use. Continuous photographic recording of the intensity of various spectral lines has also been used [3]. The plates were exposed for a constant interval and the developed image-densities compared. In this way a curve of average activity during successive intervals of time can be plotted.

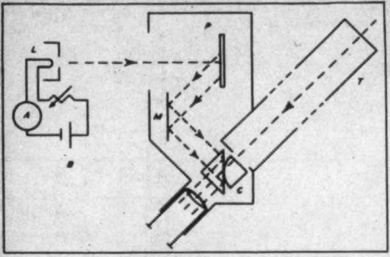

FIG. 1—SCHEMATIC DIAGRAM OF PHOTOMETER

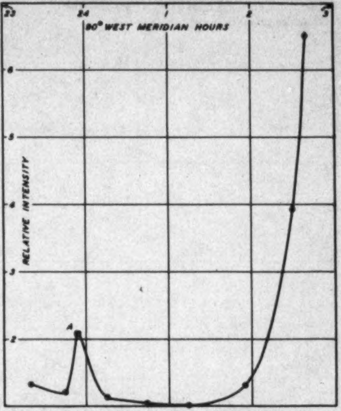

FIG. 2—SKY-INTENSITY FOR NIGHT WITH MINIMUM AURORAL ACTIVITY; FORMATION AND DECAY OF A FAINT SURFACE IS SHOWN AT A

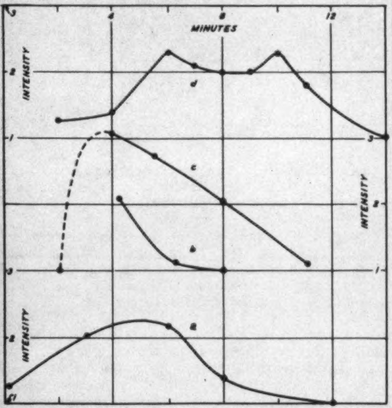

FIG. 3—(a, b, c, d) FORMATION AND DECAY OF TYPICAL DIFFUSE SURFACES AND BANDS

The above methods are not very useful for investigating the faint diffuse surfaces which accompany auroral displays. It was consequently thought worth while to attempt photometric observations of sky-brightness in the auroral zone in the hope that this type of measurement might lead to a better knowledge of the brightness-variations of the faint surfaces, and also might give a fairly continuous record of activity in a particular region of the sky.

For this purpose a photometer was constructed and taken to Churchill in northern Manitoba (94° 12' west, 58° 47' north) in the summer of 1938. A schematic diagram of the apparatus is shown in Figure 1. A standard Lummer-Brodhun photometer-head was altered in the manner shown. Light from the small lamp, L, illuminates the diffusing screen, P, and is reflected by the mirror, M, into the photometric cube, C. Light from the region under observation which was limited in extent by the tube, T (100 cm long, 5 cm internal diameter), illuminates directly the central portion of the field in view. Variations in brightness were measured in terms of the position of L. The current through L was maintained constant during any set of observations. The constancy of this standard was also checked by regular determinations of sky-brightness in regions far removed from any auroral activity. Filters were placed in the two light-paths to obtain a color-match. It is obvious that variations in any portion of the visible spectral range can be followed in this way, but in most of this preliminary work filters isolating the region 5000 to 6000 Å were used. Since all but the very active auroras maintained the characteristic greenish color throughout the night, it was usually only necessary to use a filter in the comparison-side. The entire photometer-unit was mounted on a heavy tripod and could be easily turned in any direction.

In addition to the variations in isolated regions, an instrument of this kind is suitable for determining the total illumination at the Earth's surface by sighting it on a diffusing plate placed in an exposed position. A comparison of this illumination with the brightness of different parts of the sky would be of considerable interest. Unfortunately, no records of this kind were made. The total intensity was simply estimated roughly on the conventional arbitrary scale of 0, 1, 2, 3, 4.

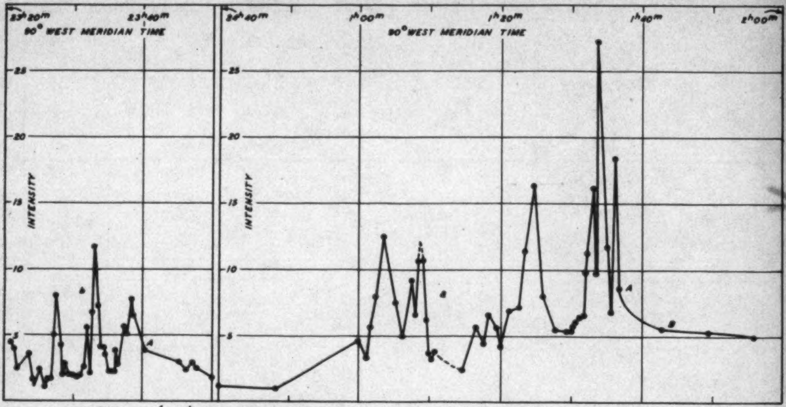

FIG. 4 — (a, b) RECORDS OF INTENSITY-VARIATIONS DURING TWO ACTIVE DISPLAYS

A typical curve of sky-brightness in the region of the Pole Star on a night with no appreciable activity is shown in Figure 2. A faint diffuse surface which happened to appear in the field of view is recorded at A and the dawn by the steep increase on the right.

Records showing the formation and decay of faint diffuse surfaces are given in Figure 3 (a, b, c, d). These curves were taken on different nights and at different times. It was found to be rather difficult to observe the initial rate of formation, since these surfaces appear at any point in the sky and are usually not noticed at first. They had no noticeable structure but resembled diffuse clouds or bands and remained approximately fixed in position.

Records of brightness throughout two auroral storms are shown in Figure 4 (a, b). In both cases the photometer was pointed toward a region in which previous experience had shown that there was not likely to be any appreciable change in color during the display. The direction for Figure 4 (a) was west altitude 35° and for (b) northwest altitude 35°. A comparison with the visual estimates indicates that the activity in this isolated region follows, in a broad sense, the total general activity. It is not to be expected that a maximum of brightness in an isolated region would necessarily correspond to a maximum of total intensity, since much of the variation is due to rapid movements of luminous surfaces across the field of view. It seemed, however, that a great increase in activity, both as regards rapidity of change and increase in maximum brightness, was rather general throughout the total region covered by the display. At A in Figure 4 (both a and b) all distinct forms had disappeared from the field of view, leaving a greatly increased background which decayed slowly. The general activity in the display shown in (a) was much greater than that of (b). This probably accounts for the much slower rate of decay of this background-luminosity. At the point A in (a) there were still a few rapidly moving curtains in the region of the zenith. At B all violent activity had ceased, leaving the sky covered with diffuse, poorly defined, luminous clouds.

For observations of active displays it is very important to be able to determine the brightness quickly. Readings could be taken and recorded with this photometer at intervals of five to ten seconds. This means, of course, that some of the fine structure of the display will be lost if the field of view covers a very active part of the sky. However, in the regions chosen in Figure 4 the changes are quite faithful representations of the actual variations.

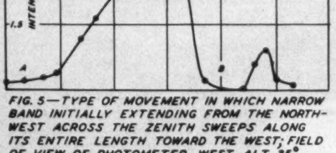

FIG. 5—TYPE OF MOVEMENT IN WHICH NARROW BAND INITIALLY EXTENDING FROM THE NORTHWEST ACROSS THE ZENITH SWEEPS ALONG ITS ENTIRE LENGTH TOWARD THE WEST; FIELD OF VIEW OF PHOTOMETER, WEST ALT 35°

The most noticeable feature of these records of active displays is the very rapid variation in brightness and the increase of background-luminosity which persists for some time after the display has ceased. It seems possible that this increase in background-luminosity might be connected in some way with the long-continued magnetic perturbations which often appear in the records taken in northern latitudes [1]. With this in mind, magnetic records of the Sitka and Meanook observatories covering the period of these two displays were examined. For the storm shown in Figure 4 (a) there is a change in declination in an otherwise normal record at the time of the storm-maximum just before the point A. The agreement is not so good in the other case (b), the change in declination occurring some minutes before the time of maximum activity as if the storm had started in the west and moved toward Churchill. For this type of analysis records of total sky-brightness would be much more useful. It is hoped that measurements of this kind for a number of displays can be obtained in the near future.

In Figure 5 is shown a record of a rather peculiar type of display often observed at Churchill. During the course of an evening a narrow band showing considerable activity will form, extending usually from low in the northwest across the zenith. Rather suddenly, without any noticeable warning, the band appears to disintegrate, spreading rapidly along its entire length toward the west. Figure 5 shows the movement of this diffuse cloud across the field of view of the photometer, which was pointed west at an altitude of 35°. The cloud just appears at A and has completely crossed the field of view at B, leaving no appreciable increase in background. While these preliminary observations have yielded no new information concerning the aurora, they show that the photometer can be used to advantage in the investigation of luminous variations as a function of the time. It should be mentioned that some of these observations were taken at the time of the full Moon.

In addition to the kind of observations reported above, it would be of considerable interest to determine the activity in the red spectral region, as well as in the green, and to measure the simultaneous variations along a single ray or bundle of rays. This might be of some assistance in determining the mechanism of light-production in the aurora.

We would like to express our appreciation of the many kindnesses shown to us by the people of Churchill and The Pas. We also wish to thank Dr. R. M. Stewart, Dominion Astronomer, for the Meanook records, and Rear Admiral L. O. Colbert, Director of the United States Coast and Geodetic Survey, for the Sitka records. This work was partially supported by a grant from the Virginia Academy of Science and the Research Fund of the University of Virginia.

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[1] For example, British Polar Year, Fort Rae, v. 1, 1937.
[2] French Polar Year, Deauvillier, J. Phy. Radium, v. 5, p. 398, 1934.
[3] B. W. Currie and H. W. Edwards, Terr. Mag., v. 41, p. 265, 1936.

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## PROGRESS-REPORT OF THE NATIONAL GEOGRAPHIC SOCIETY-CORNELL UNIVERSITY STUDY OF AURORA

C. W. Gartlein

The National Geographic Society and Cornell University have set up a three-year comprehensive program of research on the aurora borealis, as seen in lower latitudes, 40° to 45° north. Parallactic height-measurements are made from four stations. The base-line, Cornell Aurora Observatory, Ithaca, New York (76° 29' west, 42° 29' north), to the tower of Colgate Memorial Chapel, Hamilton, New York (75° 33' west, 42° 49' north), is equipped with special auroral cameras with lenses of 45-mm focus and aperture F/2. The base-line, Fuertes Observatory, Ithaca, New York (76° 29' west, 42° 27' north), to Smith Observatory, Hobart College, Geneva, New York (77° 00' west, 42° 53' north), is equipped with auroral cameras loaned by the Auroral Committee of the International Union of Geodesy and Geophysics. Each camera takes six separate photographs on a plate 9 by 12 cm. The plates used are 1-C special, panchromatic, and 1-G special green-sensitive, specially coated by the Eastman Kodak Company. These plates have greater speed and finer grain than any other high-speed plates known to be available. About 500 photographs were taken between September, 1938, and April 24, 1939, of which about 100 pairs are suitable for height-measurement. No height-measurements have yet been made from these negatives (see Fig. 1).

Two spectrographs have been built. The continuous running spectrograph moves a plate through the focal plane to give an effective exposure of about one-half hour with the single

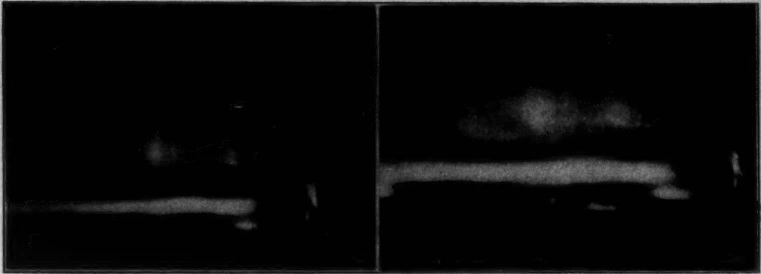

FIG. 1—FINE AURORAL DISPLAY, $10^{h}09^{m}35^{s}$ 75° WEST MERIDIAN TIME, MARCH 28-29, 1939; (A) ITHACA, NEW YORK, (B) HAMILTON, NEW YORK

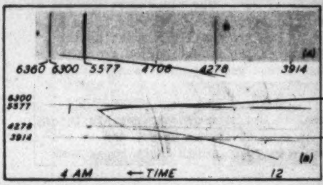

FIG. 2—(A) AURORAL SPECTRUM, MARCH 28, 1939 (2-PRISM SPECTROGRAPH, ACTUAL SPECTRUM 14 MM LONG); (B) CHANGES AURORAL SPECTRUM WITH TIME $0^{h}$-$4^{h}$, APRIL 22-23, 1939

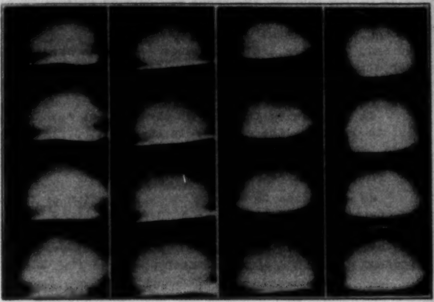

FIG. 3—DEVELOPMENT HOMOGENEOUS BAND, $22^{h}05^{m}$ 75° WMT, MARCH 28, 1939, BY AUTOMATIC CAMERA [EXPOSURES FROM TOP LEFT TO LOWER RIGHT AT 30-SECOND INTERVALS]

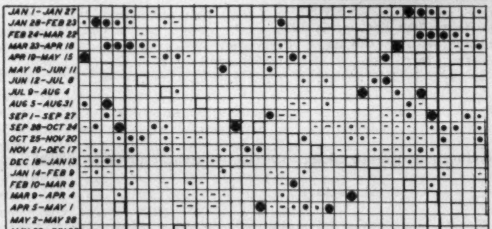

FIG. 4—CHART SHOWING AURORAS SEEN JANUARY 1, 1938 TO APRIL 23, 1939 [SIZES OF DOTS INDICATE MAGNITUDE OF DISPLAY ON SCALE I TO IV; SMALL LINES INDICATE GREEN LINE WAS VISIBLE IN SPECTROSCOPE; OUTLINED SQUARES ARE NIGHTS OF FULL MOON; DATES REFER TO SQUARES INSIDE VERTICAL LINES]

prism and camera lens of 5-cm focus and aperture F/1.65. The precision-spectrograph contains two prisms with 10-cm faces, collimator of 38-cm focus, and camera lens of 10-cm focus and aperture F/1.65. The optical parts of both instruments were made by the Bausch and Lomb Optical Company, and the mechanical construction was by the shops of the Physics Department of Cornell University (see Fig. 2).

An automatic camera has been made to take photographs, usually of 30-second duration, at 30-second intervals with a lens of 15-mm focus and aperture F/1.5 on 16-mm film. This has been operated to study the time-development of various auroral forms. While the results obtained have been very satisfactory (see Fig. 3), the camera should be made more flexible.

An automatic photoelectric intensity-meter is being built and should be placed in operation during July, 1939. A simple comparison-type photometer, which uses the light of a constant-voltage lamp through a mercury green filter, provides a means of measuring auroral brightness with sufficient precision to obtain satisfactory photographic exposures.

Color-photography of the aurora is being tried with Kodachrome film and fast lenses. During April several photographs were obtained which show the pink lower borders of some homogeneous arcs.

Visual observations are being made by the four parallax-stations as well as by members of the American Meteor Society, of the American Association of Variable Star Observers, of the National Geographic Society, and of the Royal Astronomical Society of Canada. Three airplane-lines (Transcontinental and Western Air, Inc., Northwest Airlines, and Western Air Express) are sending in reports which ensure continuity of observation during cloudy weather (see announcement in Terr. Mag., v. 44, pp. 43-49, 1939, for details of this part of the program).

The number of such visual observers is being increased in an effort to draw boundaries around given auroral displays.

The value of such wide-spread observers is shown by the observations of the aurora of September 27-28, 1938. The two diffuse surfaces seen at $10^h\ 40^m$ 75° west meridian time from many points in northeastern United States were located north of latitude 43° and yet were observed in north-central Texas at an elevation of about 20°. In spite of the crudeness of the observations we may be certain that the summits of the surfaces were 500 km above the Earth and possibly as high as 800 km. The yellowish rays were also seen and were much higher.

During this same time the earth-potential records of the Bell Telephone Laboratories showed a peak which was three times as high as any other peak that night and was half as high as the highest maximum ever recorded.

Auroras seen at Ithaca are more frequent and brighter than is commonly supposed. Data taken in New York State between 1825 and 1851 indicate that from 25 to 100 auroras occur each year. Own own data from January 1, 1938, to April 23, 1939, show that of 70 displays visible nine were brilliant (see Fig. 4). The auroral green-line or a weak glow was seen on many other nights.

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## NITRIC OXIDE IN THE UPPER ATMOSPHERE

Joseph Kaplan

The promise of a complete reproduction in the laboratory of the role played by oxygen in the Earth's upper atmosphere has been shown in a series of experiments, which are now under way. The results already obtained are of such interest that a preliminary report is presented here. All of the observations have been made in extremely weak electrical discharges and in the afterglows which were generated by such weak discharges. Only a trace of oxygen was present in the tubes which contained nitrogen. The two tubes in which these observations were made are the ones in which the nitrogen line $^2P-^4S$, λ3466.4 Å was first studied. It may be mentionedthat this discovery led to the identification of the corresponding line in the auroral spectrum and thus to the discovery of atomic nitrogen in the Earth's upper atmosphere.

About four years ago I studied the weak blue afterglow which accompanied very feeble electrical discharges in extremely pure nitrogen. The spectrum of the afterglow was marked by the large relative intensity of the Vegard-Kaplan bands. The intensity was so large that those bands were as prominent as the normally strong second-positive group. Addition of small amounts of pure oxygen resulted in the production of the green auroral line with a relative intensity very much like that in the light of the night-sky. These experiments did much to direct attention to the Vegard-Kaplan bands during the last few years and the identification of this system in the light of the night-sky is the result. Much credit for this should go to the group of French astronomers and physicists including Dufay, Cabannes, Gauzit, Bernard, and Dejardin, and others.

During the course of these experiments the most striking observation was the absence of the beta bands of nitric oxide. These bands are quite strong in the spectrum of the Lewis-Rayleigh glow, whenever oxygen is present even in extremely small amounts, and their absence from auroral and night-sky spectra has always puzzled this writer. No one else seems to have stressed this point and yet it is a striking one, especially to those with experience in the laboratory with nitrogen afterglows. The new experiments to which we referred earlier give the answer to the apparent absence of nitric oxide.

The tube in which the answer to the nitric-oxide question was just obtained is one which was originally at such high pressure that the $^2P$-$^4S$ line of nitrogen was strong. As the pressure was diminished by the cleaning up of the nitrogen, the λ3467 line and the Vegard-Kaplan bands grew relatively weaker and the second-positive, Goldstein-Kaplan, and first-negative bands relatively stronger. By diminishing the exciting current, the afterglow grew richer in the Vegard-Kaplan bands and the λ3467 line until with an extremely weak current, the spectrum of the glow became practically a pure Vegard-Kaplan and 3467 excitation. The normally strong second-positive bands almost disappeared. The remarkable nature of this observation will be recognized when it is realized that the $^2P$ level and the $A^3\Sigma$ level, the origins of the 3467 line and the Vegard-Kaplan bands, respectively, are metastable levels. Thus we have forbidden lines and bands providing nearly all of the radiations in this afterglow-spectrum. The large intensity of the Vegard-Kaplan bands relative to the second-positive group agrees perfectly with Gauzit's recently published list of night-sky radiations.

Fortunately, there was a trace of oxygen left in the tube from the clean-up process and, although it failed to show itself in high-current afterglows as indicated by the complete absence of nitric-oxide bands on their spectra, in the above-mentioned weak afterglow the nitric-oxide gamma bands were present with an intensity about equal to that of the Vegard-Kaplan system. The beta bands were missing. The strongest members of the beta bands lie above λ2900 and those of the gamma system below this wave-length. These observations show clearly why no nitric-oxide bands are observed in night-sky spectra. The gamma bands are undoubtedly present, but the limit of observation set by the presence of ozone prevents their observation. The beta bands are not excited in a mixture of metastable $N_2$ molecules, N atoms and oxygen, and hence nitric oxide cannot be observed by means of this system. This observation adds nitric oxide to the list of possible constituents in the upper atmosphere.

To complete the story it is necessary to discuss the other indications of the presence of oxygen in this weak afterglow. A careful examination of the spectrum showed a weak radiation near the position of the 2977 second-positive band but a little to the short wave-length side. This has now been identified as the hitherto unreported line λ2972.3 corresponding to the transition $^1S_0$ - $^3P_1$ in atomic oxygen. As proposed by Gauzit, this corresponds to the radiation at 2975 observed by him in the light of the night-sky. Further study of this new "auroral" ultraviolet line of oxygen will be made. Almost conclusive evidence that the line that we have observed is really the new oxygen line is provided by the observation of the green auroral line in the same tube with an intensity corresponding roughly to that predicted by theory.

This experiment, as can be readily concluded from this brief report, has already been rich in information concerning the role of oxygen in the upper atmosphere. It is even richer in suggesting that the relative intensities of the beta and gamma systems of nitric oxide in the various nitrogen afterglows will help explain the mechanism of these glows and in that way give us further clues to mechanisms in the upper atmosphere.

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## THE SPECTRA OF BRIGHT CHROMOSPHERIC ERUPTIONS FROM λ3300 TO λ11500

R. S. Richardson and R. Minkowski

Ordinarily when we view the upper atmosphere of the Sun, or chromosphere, with the spectrohelioscope, there is no feature on the disk so conspicuous that it immediately attracts our attention to the exclusion of everything else.

But if we watch the Sun for several hours, or days, or weeks with the spectrohelioscope, we are apt to be startled by the sudden appearance of an intensely brilliant cloud over a group of spots. Within ten minutes or even less, the cloud may become ten to twenty times brighter than its surroundings. Then it begins to fade, and fifteen minutes or an hour later will have vanished completely, leaving the region apparently the same as it was in the beginning.

These sudden outbursts are the so-called bright chromospheric eruptions. The first one on record occurred in 1859, and was so intense that it was visible directly on the disk without spectroscopic aid. Since then many others have been caught, usually by accident, while the observer was engaged in some other work. No special effort was made to study them systematically until 1931, when Hale distributed spectrohelioscopes to observers all around the world, thus starting a campaign to keep the Sun under a continuous watch throughout the entire 24 hours.

In 1935 new incentive was given to this work when J. H. Dellinger called attention to a series of remarkable fade-outs of high-frequency radio signals, and suggested that they might be connected with the bright eruptions previously discussed in detail by Hale. This idea has been abundantly confirmed, so that there is now excellent evidence for the belief that energy emitted by the bright eruptions, and travelling with the velocity of light, produces the sudden fade-outs, and also a disturbance in the Earth's magnetic field of a type previously unrecognized.

The terrestrial effects are attributed to an increase of ionization in the lowest level of the ionosphere, caused by an intense burst of ultraviolet light from the eruption. On this basis, the emission most commonly observed in the Balmer lines is of minor importance, the really effective radiation coming from the unobservable ultraviolet part of the spectrum.

This hypothesis can best be tested by studying the spectra of the bright eruptions. Observations were made for this purpose at Mount Wilson from July 1 to December 10, 1938, with a concave-grating spectrograph including an all-mirror optical system, from λ3300 to λ11,500. The only lines found to be affected are those of helium, hydrogen, and ionized calcium. There was no evidence of emission in the continuous spectrum, as one would expect if black-body radiation played an important part in the eruptions.

By far the most interesting result obtained, and one which was not anticipated, was the appearance in emission on the disk of the helium line at λ10,830 in an eruption of intensity 3 on December 7, 1938. This is the only case of a line showing in the solar spectrum in emission on the disk without absorption. The helium lines at λ6678, λ5876, and λ4471 showed in an eruption at the limb, but not on the disk.

Emission could be traced in the Balmer series from $H\alpha$ down as far as $H\iota$. There was no trace of the Paschen lines at λ10,049 and λ10,938 on the disk in the same eruption that easily showed the λ10,830 line of helium.

The infra-red triplet of ionized calcium, and H and K in the violet, show in emission even in small eruptions. Emission was also detected in the ionized calcium line at λ3737, but its companion at λ3706 could not be found.

The most likely source of the ionizing radiation is from $Ly\alpha$ at λ1216, whose presence is indicated by the great intensity of $H\alpha$. But just as the emission of $H\alpha$ is followed by that of $Ly\alpha$, so must the emission of λ6678 of helium be succeeded by λ584 of helium. This line is capable of ionizing directly all constituents of the Earth's atmosphere with the exception of helium. Radiation of this wave-length is absorbed strongly in the atmosphere. It is not to be expected, therefore, that absorption of λ584 will play an important role in the changes in the lower ionosphere which are mainly responsible for the fade-outs. But its effects may be of importance for those variations of ionization in the higher regions that accompany the fade-outs.

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## OBLIQUE-INCIDENCE IONOSPHERIC DATA AND THE LORENTZ POLARIZATION TERM

Newbern Smith

(Abstract)

The force on an electron in an ionized medium may be written $E + 4\pi aP$, where E is the electric force, P is the polarization of the medium, and a is a quantity which theoretically should have either the value 1/3 (Lorentz theory) or 0 (Sellmeyer theory). A clear-cut distinction exists between maximum usable frequencies for radio sky-wave transmission as calculated from vertical-incidence ionospheric data on the basis of the two theories. This distinction between the two theories has a more general application and is less subject to ambiguous interpretation than is the case with most of the radio experiments, bearing on the question, that have previously been reported.

The measurements reported in this paper yield values which it is necessary to assume for the quantity a in order to obtain agreement between observed and calculated times of beginning and ending of E-layer transmission on 6060 kc/sec over a distance of 650 km. The transmission-path over which measurements were made was nearly transverse to the Earth's magnetic field,

thereby eliminating much complexity in calculation.

The difference between calculated maximum usable frequencies for this transmission-path for $a = 0$ and $a = 1/3$ is about 17 per cent. The mean of over 250 observations indicates a value of $a$ of about 0.01, not significantly different from zero. It would appear, therefore, that in at least this case of oblique-incidence radio transmission the Sellmeyer, and not the Lorentz, theory, is consistent with the observations.

The complete paper is to be published in the Journal of Research of the National Bureau of Standards.

National Bureau of Standards,
Washington, D. C.

## ATMOSPHERIC-ELECTRIC RELATIONS IN QUIET AIR

K. L. Sherman

(Abstract)

The theory describing the electrification of the lower atmosphere has been quite completely developed for quiet-air conditions, but it has been rather generally assumed that eddy-diffusion or mixing processes would so predominate as to render the theory of little use for actual conditions in the atmosphere. However, it seems reasonable to expect that at certain times the assumptions underlying such a theory would be tenable. Observations made at College, Alaska, during the International Polar Year, indicate that during the winter the extremely quiet-air conditions found there did result in good agreement between the observed and predicted relation between the ratio of the positive to negative conductivity and the potential-gradient. It is believed that careful scrutiny of the data from other locations would show that the theory is more generally applicable than has previously been assumed.

The complete paper will be published in the Journal of Terrestrial Magnetism and Atmospheric Electricity.

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## SOME EFFECTS OF METEOROLOGICAL DISTURBANCES ON THE ELECTRICAL CONDITION OF THE LOWER ATMOSPHERE

O. W. Torreson and G. R. Wait

(Abstract)

The Department of Terrestrial Magnetism of the Carnegie Institution of Washington has obtained continuous records of potential-gradient and of positive and negative conductivities of the atmosphere at Huancayo (Peru) and Watheroo (Western Australia) since 1924. At both observatories the observations from December to March are conspicuously disturbed year after year--at Watheroo by smoke from burning brush and from fields burned over by farmers after harvest, and at Huancayo by almost daily thunder-storms.

At Watheroo, the smoke arrives at the station almost daily in the middle or late afternoon, brought in by systematic change in wind-direction. Comparison of 66 non-smoky days with 120 smoky days in March for the ten years 1924-1933 shows potential-gradient to be higher on smoky than on non-smoky days--about 50 per cent higher soon after the arrival of the smoke and remaining so until daylight next morning, then falling to 15 or 20 per cent higher for the remaining daylight hours until the next smoke-infusion. The conductivities, on the other hand, both positive and negative, have the higher values on non-smoky days, some 50 per cent in the late afternoon and at night and 15 or 20 per cent in the daylight hours. Hence, the computed air-earth-current diurnal-variation curves for smoky and non-smoky days are found to be the same in magnitude from hour to hour through the day, the maximum in each being at $5^h$ and the minimum at $17^h$, 120° east meridian time. The maximum and minimum values of air-earth current are, respectively, $11.5 \times 10^{-7}$ and $8.5 \times 10^{-7}$ ESU. One must conclude, since the current is the same on smoky and

non-smoky days, that the daily intrusion of smoke-pollution is confined to such a low level in the air that it cannot appreciably affect the total resistance of the air-column above the station. However, there are indications that some little transference of smoke-pollution to higher levels takes place through the smoky months, sufficient to make the monthly mean values of air-earth current in those months somewhat lower than the values in non-smoky months.

At Huancayo, particles in the air, which serve as centers for condensation of moisture, have been counted daily since 1932 at $8^h$, 75° west meridian time, with an Aitken nuclei-counter. Monthly means of nuclei-content in the years 1932 to 1936 and of corresponding computed values of air-earth current show relation to each other and to rainfall through the year. In the rainiest months of December to March the air-earth current is highest, averaging about $15 \times 10^{-7}$ ESU, while the nuclei-content is lowest, being less than 10,000 per cc. In the driest months from May to August the air-earth current is least, about $10 \times 10^{-7}$ ESU while the nuclei average 25,000 or more. Annual variation in air-earth current and rainfall is similar in years prior to 1932, implying that nuclei-concentration varied in those years in a manner similar to that in the later years. For Huancayo, it must be concluded that nuclei generally exist in significant quantities to heights in the atmosphere sufficiently great to appreciably affect the total resistance of the air-column at that station and that the annual variation in nuclei-concentration therefore is a factor in the production of an annual variation in the air-earth current.

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## A METHOD OF CORRECTING THE FARNHAM MAGNETIC DATUM FOR SECULAR VARIATION

F. C. Farnham

### (Abstract)

This paper is a continuation of a paper "A reference-datum for magnetometer-surveys" presented at the New York meeting of the American Institute of Mechanical Engineers in February, 1939. The present paper deals with a method of taking secular variation into account in preparation of magnetometer-maps. The proposed method consists of using correction-factors for time-variation in connection with the correction-factors for latitude and longitude. Plates showing a comparison of the computed and observed values of annual change are given.

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## THE BASE-LINE DRIFT OF SCHMIDT VERTICAL MAGNETIC FIELD-BALANCES

Victor Vacquier

### (Abstract)

The creation of a network of magnetic stations at which the vertical magnetic intensity is measured with better precision than can be done with the earth-inductor would be useful in mineral prospecting and would also be indispensable for unifying the vast amount of observational material gathered by private organizations. This unification would be very valuable to geomagnetic science as well as to the study of large-scale geological problems. It is estimated that by operating Schmidt balances in groups of three or four instruments and by standardizing them at magnetic observatories every three months, it would be possible to reduce to less than five gammas the contribution of base-line drifts to the probable error of an absolute determination of the vertical magnetic intensity at field-stations. The data on which this estimate is based are given in full so as to enable the reader to arrive at his own conclusions.

Recently it has been suggested [V. Vacquier, Application of vertical variometer measurements to the study of secular magnetic variations, Trans. Amer. Geophys. Union, 19th Annual Meeting, 1938, pp. 206-210] that more accurate magnetic measurements might provide a firmer foundation for our speculations on the origin of the Earth's magnetic field and of its secular variation. It has been shown that magnetic measurements available at present give us no clue, for example, to the maximum sharpness with which secular magnetic variations are occurring.

Furthermore, it was pointed out that even in the southeastern United States, where the density of repeat-stations is high, a very general picture of the secular variation of the vertical magnetic intensity could be obtained only by averaging the results of a great number of adjacent observations. According to Captain N. H. Heck [oral communication to the writer], Chief of the Division of Terrestrial Magnetism and Seismology of the United States Coast and Geodetic Survey, this can be ascribed not only to the unfortunate location of some of the repeat-stations, but also to the poor precision with which the vertical magnetic intensity is measured by conventional, so-called absolute, instruments. In his opinion the preparation of reliable secular-variation charts of the United States every ten years would be facilitated by an increase in observational accuracy.

The necessity of providing surveyors and navigators with accurate declination-charts was, of course, the main purpose of magnetic surveys conducted by the governments of civilized countries, the data on the other magnetic elements being gathered as a by-product for purely scientific ends. With the advent of magnetic prospecting, the vertical-intensity charts became indispensable to the prospector for the purpose of eliminating from his data the normal change of the geomagnetic field. For this use the available charts are satisfactory. However, if they were more accurate and more detailed, they could furnish the means for selecting areas where surveys conducted for the purpose of locating minerals would be most effective and thus reduce the cost of such prospecting operations. It should not be overlooked that, to supplement the information obtained from surface geologic mapping, geologists are using geophysical data more and more in their speculations.

Furthermore, the creation of a network of stations where the vertical intensity is accurately known would make it possible at a later date to assemble the enormous body of observational material which has been gathered by private concerns. Much of the value of these data, to collect which has cost millions of dollars, will be lost to geomagnetic science unless accurate information on secular magnetic variations is obtained in the near future.

Although the need for such a program has been felt for some time, the possibility of initiating it seemed to be remote because of the lack of improvement in the methods of measuring absolutely the vertical magnetic intensity since the year 1913 when the Department of Terrestrial Magnetism of the Carnegie Institution of Washington devised a portable earth-inductor. In view of this unfortunate situation, Dr. E. A. Eckhardt, Vice-President of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, has suggested that, as a temporary expedient until a more suitable instrument is built, Schmidt vertical field-balances might be used to increase the precision and the speed of the mapping of the vertical magnetic intensity. This might be accomplished by beginning and ending each series of traverses at a magnetic observatory. Before such a procedure can be recommended it is necessary to investigate the amount and the character of the zero-drift of Schmidt balances. This constitutes the purpose of the present communication.

During the last six years the Gulf Research and Development Company has operated 23 Schmidt balances. All of them were not in service simultaneously. These instruments consist of Askania housings and optical systems purchased about 1927 and fitted with Askania temperature-compensated magnet-systems. Thicker cork insulation was installed around the housing and a heavier tripod was provided. The balances are calibrated by means of a Helmholtz coil and a current-measuring potentiometer to at least one part in 2,000. Changes as small as 0.5 gamma in the Earth's vertical magnetic intensity at any one place can be detected, and the probable error of a single field-observation referred to a nearby base is one gamma.

Since the data used to investigate the drift of the Schmidt balances were obtained in geophysical-prospecting operations, a short description of such operations is here given. From two to five instruments are commonly assigned to a party engaged in magnetic prospecting. On each party one instrument (called base-instrument) is kept stationary at the base-station and is read every ten minutes to determine the time-variations of the geomagnetic field, while the other instrument or instruments are observing within a radius of about 20 miles. Any one base-station is used for three weeks or longer. When the area around it has been covered, another base-station is established in adjacent territory. At the beginning and at the end of each day's work, the field-balances are compared with the base-instrument at the base-station. The difference in scale-reading between any field-instrument and the base-instrument should then stay constant from day to day, if neither instrument drifts. If this difference is variable, it is, of course, impossible to impute the drift to one particular instrument in case only two instruments are available. If, in addition to the base-instrument, two or more field-instruments are in operation, it is usually possible to decide which instrument is drifting. Although the differences between the base- and the field-instruments suffer discontinuities each time the magnet of the base-instrument is readjusted, these discontinuities should be and usually are of the same magnitude for each field-balance and do not constitute a break in the record. These considerations will be clarified when actual examples of how the data were treated are discussed.

From the mass of available observational material the data from two groups of balances were selected because these groups consisted of the largest number of instruments operated together and because they represent two extremes of climatic and operating conditions. One group was used from May 21, 1935, to June 22, 1938, in eastern Venezuela where the climate is humid and corrosive, where the diurnal temperature-range seldom exceeds 10° C, and where most of the territory had to be covered on mule-back. The other group was operated in eastern Colorado from April 23, 1935, to July 24, 1936, where dust-storms with high winds were frequent, where a diurnal temperature-range of 20° C was not uncommon, and where automobiles were used exclusively for transportation.

The difference each day between a field-instrument and the base-instrument is available from the original data and generally is taken as the average of the comparisons in the morning and evening. The value of this difference expressed to the nearest gamma was tabulated for each field-balance as illustrated in Table 1 for a small amount of the Colorado data. It can be seen that from December 17 to 20, 1935, the differences between the base-instrument and the four field-instruments remained fairly constant, but on December 31 the differences given by instruments 14, 21, 15, and 23 changed, respectively, by 18, 16, 16, and 17 gammas. We conclude that the compensating magnet of the base-instrument has been shifted because the change was abrupt, and because the four other instruments were in agreement as to its magnitude. The tabulated differences, exhibited in Table 1, were plotted against calendar days as abscissae. Whenever a shift like the one just mentioned occurred, a constant equal to the negative of the average change (17 gammas in the above example) was added to the base-line of the ordinates of each plot. Figure 1, which contains the material of Table 1, gives a small portion of the Colorado data plotted in this manner. Unfortunately, in certain cases it is uncertain whether the base-instrument shifted its zero because of an adjustment of the compensating magnet or for other reasons, since the parties were not instructed to note when the position of the compensating magnet was changed. The fact that the change is abrupt is not a sufficient condition for deciding the mode of its occurrence. It is likely that in certain cases the base-lines of the curves should not have been altered. On the other hand, a small number of errors was probably made in the opposite direction.

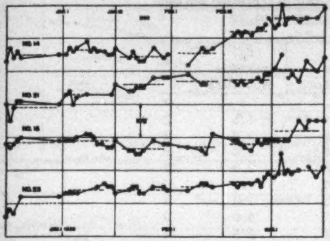


*FIG. 1—DAILY DIFFERENCES BETWEEN FIELD-INSTRUMENTS OF COLORADO SURVEY AND THEIR ASSOCIATED BASE-INSTRUMENT (NUMBERS IDENTIFYING GRAPHS ARE SERIAL NUMBERS OF THE FIELD-INSTRUMENTS)*

Table 1--Differences between the base-instrument and each field-instrument

| Date | Instrument number | | | |
|---|---|---|---|---|
| | 14 | 21 | 15 | 23 |
| 1935 | γ | γ | γ | γ |
| Dec. 17 | 48 | 413 | 423 | 482 |
| 18 | 51 | 409 | 422 | 483 |
| 19 | 49 | 407 | 421 | 480 |
| 20 | 51 | 407 | 420 | 478 |
| 31 | 33 | 391 | 404 | 461 |
| 1936 | | | | |
| Jan. 2 | 33 | 388 | 404 | 460 |
| 3 | 31 | 387 | 404 | 460 |
| 4 | 32 | 391 | 404 | 460 |
| 5 | 31 | 389 | 403 | |
| 8 | 29 | 388 | 402 | |
| 9 | 32 | | 402 | |
| 10 | 31 | | 403 | |
| 11 | 32 | | 405 | 458 |
| 13 | 32 | | 405 | 457 |
| 14 | 33 | | 406 | 458 |
| 15 | 33 | 388 | 406 | 458 |
| 16 | 31 | 385 | 404 | 460 |
| 20 | 34 | 387 | 407 | 459 |
| 21 | 32 | 387 | 407 | 458 |
| 22 | 34 | 386 | 408 | 458 |
| 23 | 35 | 386 | 408 | 460 |
| 24 | 35 | 386 | 407 | 470a) |
| 27 | 31 | 383 | 404 | 468 |
| 30 | 34 | 383 | 405 | 468 |
| 31 | 33 | 383 | 405 | 469 |

a) Instrument readjusted.

Fortunately, the field-instruments are not readjusted as often as the base-instrument, as they are equipped with carefully calibrated compensating magnets and possess a range of about 2500 gammas. Some of them have been in operation for several months without being opened for repair. The shift of the zero of a field-instrument produced by its readjustment could be clearly ascertained every time, not only from a sudden discontinuity with respect to the base-instrument which does not appear in the comparisons of the other field-instruments with the base-instrument, but also because the constants of this field-instrument, which are always recorded on the data-sheets, suffer a sudden change. The amount by which the zero of the instrument was disturbed was computed by comparison with the other variometers, so that in most cases it was

Table 2--Half-monthly averages of the difference between the base-instrument and instrument 10

| Month | A, 1/2-month average | n, No. of days | d, mean departure | $d_m$, maximum departure | r, range |
|---|---|---|---|---|---|
| 1933 | γ | | γ | γ | γ |
| 4 | 68.5 | 6 | 0.8 | 1.5 | 3 |
| | 69.0 | 9 | 0.8 | 2.0 | 3 |
| | 70.0 | 8 | 2.6 | 5.0 | 8 |
| 5 | 81.0 | 10 | 2.3 | 5.0 | 10 |
| | 84.0 | 9 | 0.0 | 0.0 | 0 |
| 6 | 86.0 | 7 | 1.3 | 2.0 | 4 |
| 7 | 89.0 | 7 | 1.7 | 4.0 | 7 |
| | 77.5 | 13 | 1.1 | 2.5 | 4 |
| 8 | 83.0 | 0 | (interpolated) | | |
| | 89.0 | 6 | 2.3 | 7.0 | 10 |
| 9 | 97.5 | 11 | 1.3 | 4.5 | 6 |
| | 100.5 | 10 | 1.0 | 2.5 | 4 |
| 10 | 99.0 | 11 | 1.0 | 3.0 | 5 |
| | Mean | 7.7 | 1.32 | 3.07 | 5.07 |

Table 3--Summary of data and of instrument-performance for half-monthly periods

| Instrument number | Number of days | Days in period | $\bar{d}$, mean deviation from 1/2-monthly averages | $\bar{d}_m$, mean of maximum deviations from 1/2-monthly averages | $\bar{r}$, mean range per period | Country |
|---|---|---|---|---|---|---|
| | | | γ | γ | γ | |
| 44 | 639 | 9.00 | 1.07 | 2.43 | 3.97 | Venezuela |
| 46 | 324 | 6.35 | 1.19 | 2.29 | 3.95 | |
| 5 | 456 | 8.14 | 0.97 | 2.12 | 3.63 | |
| Total | 1419 | | | | | |
| Mean | | 7.84 | 1.04 | 2.28 | 3.85 | |
| 15 | 207 | 7.96 | 1.79 | 3.59 | 6.99 | Colorado |
| 14 | 233 | 8.32 | 1.67 | 3.58 | 5.99 | |
| 13, 23 | 171 | 7.44 | 1.28 | 2.63 | 4.49 | |
| 2 | 91 | 7.59 | 1.63 | 4.15 | 6.50 | |
| 10 | 116 | 7.73 | 1.32 | 3.07 | 5.07 | |
| 21 | 135 | 7.50 | 1.83 | 3.72 | 6.44 | |
| Total | 953 | | | | | |
| Mean | | 7.75 | 1.58 | 3.46 | 5.92 | |

possible to continue plotting the corresponding curve of Figure 1 without incurring an uncertainty greater than three gammas across the break. Whenever such a break occurred, the points in the curves of Figure 1 lying across this break were not joined together, as, for example, between January 23 to 24 for instrument 23 or between January 30 and February 6 for instrument 14. This procedure failed, of course, when too many variometers were dismantled at the same time, necessitating the treatment of subsequent data as a new series of measurements unrelated to the preceding material.

The publication of all the data in the form of Figure 1 would require too much space. They were, therefore, condensed by computing the average value of the curves of Figure 1 for every half-month. These averages are represented on this Figure as dotted, horizontal lines and were computed to the nearest half-gamma. Table 2 gives an idea of the magnitude of the departures of the daily comparisons between instrument 10 and its associated base-instrument from the half-monthly averages. In Table 2 the columns A, n, d, $d_m$, and r show, respectively: (A) half-monthly averages reckoned from an arbitrary zero; (n) the number of points from which they were computed; (d) the mean of the absolute values of the departures of the individual comparisons from the half-monthly average; ($d_m$) the maximum departure from this average; and finally (r) the total range of the oscillation during the half-monthly period. The averages of the quantities d, $d_m$, and r were computed for each field-instrument. These numbers appear in the last three columns of Table 3 and constitute the first result of the present investigation. Table 3 also gives the total number of days the instrument was in the field and the average number of such

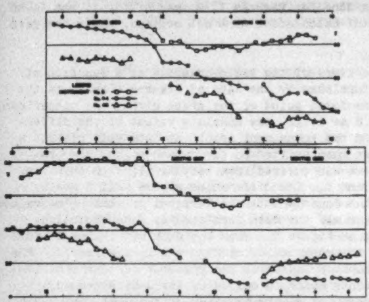


FIG. 2—HALF-MONTHLY AVERAGES OF DIFFERENCES BETWEEN FIELD-INSTRUMENTS AND BASE-INSTRUMENT, VENEZUELA SURVEY

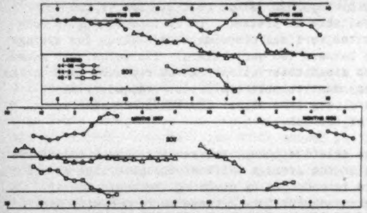


FIG. 4—DIFFERENCES BETWEEN BASE-LINE VALUES OF PAIRS OF FIELD-INSTRUMENTS OBTAINED BY SUBTRACTING THE GRAPHS OF FIGURE 2, VENEZUELA SURVEY

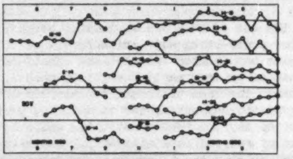


FIG. 5—DIFFERENCES BETWEEN BASE-LINE VALUES OF PAIRS OF FIELD-INSTRUMENTS OBTAINED BY SUBTRACTING THE GRAPHS OF FIGURE 3, COLORADO SURVEY

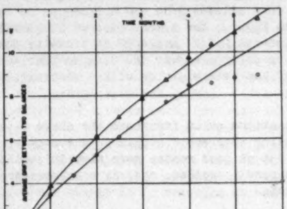


FIG. 6—AVERAGE DRIFT BETWEEN BASE-LINES OF TWO SCHMIDT BALANCES AS A FUNCTION OF TIME (UPPER CURVE IS COMPUTED FROM ALL DATA; LOWER CURVE COMPUTED ONLY FROM COMPARISONS BETWEEN FIELD-INSTRUMENTS)

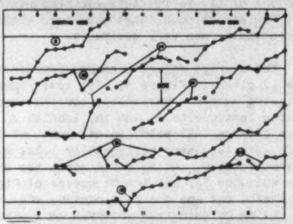


FIG. 3—HALF-MONTHLY AVERAGES OF DIFFERENCES BETWEEN FIELD-INSTRUMENTS AND BASE-INSTRUMENT, COLORADO SURVEY

days per half-monthly period. If from the data of Table 3 we wish to estimate the frequency with which daily comparisons depart by a given amount from the half-monthly average, it becomes necessary to postulate a specific distribution of the errors. If the normal law is assumed, the average error, d, in Table 3 is multiplied by 0.845 to get the probable error. The mean value of this quantity for the three instruments of the Venezuela party is 0.88 gamma, which means that on the basis of a gaussian distribution as many errors were greater than 0.88 gamma as were smaller. The instruments in the Colorado area did not perform as well as a cursory glance at the figures will reveal. This difference is attributable to the much smaller temperature-gradients prevailing in eastern Venezuela and possibly to more careful adjustment of the equipment.

To show the behavior of the base-line drift for periods longer than two weeks, the half-monthly averages defined above were plotted against time on Figures 2 and 3. The figures labeling the graphs refer to the number of the field-instrument. As before, the curves have been broken each time the field-instrument was readjusted. Figures 2 and 3 represent a condensation of all the observational material. It may be noted that in Figure 3 all curves have an upward slope, indicating that the base-instrument possessed a consistent downward drift. Each curve of Figures 2 and 3 was subtracted from the others. The results (Figs. 4 and 5) represent comparisons of the field-instruments of each group independent of the readings of the base-instrument. As mentioned before, the times at which the base-instrument was readjusted are not always definitely ascertainable, and it is believed that Figures 4 and 5 give, therefore, a truer picture of instrumental drift. It may be noted that the graphs of Figures 4 and 5 are not broken whenever one of the variometers was readjusted as was done for Figures 1, 2, and 3; for it was found that the errors thus introduced into the subsequent calculation were not serious, while the gain in continuity was very desirable.

The average relative change between the base-lines of two field-balances as a function of time is given in Figure 6. The lower curve was furnished by the data of Figures 4 and 5 in the following manner. Beginning, for instance, at the first point of the graph giving the comparison between instruments 14 and 15, labeled on Figure 5 as 14-15, the absolute values of the differences between that point (ninth month of 1935) and the subsequent points at intervals of half a month were tabulated horizontally. The origin was then shifted to the second point, the procedure repeated, and so forth until the whole curve was covered from left to right in this way. This was done for all the 25 curves of Figures 4 and 5. The differences across half a month, one month, one and one-half months, etc., were thus found written in vertical columns. The values pertaining to each time-interval were averaged over all the data furnished by the comparison-curves of Figures 4 and 5, and plotted as circles on Figure 6. When the data of Figures 2 and 3 which include the base-variometers are added in, the upper curve of Figure 6 is the result. The fact that it gives larger values for the drift probably indicates the presence of that contribution to the shift of the zero of the base-instruments which is caused by the undetected adjustments of their compensating magnets. With the exception of the behavior of the base-instrument of the Colorado troop which produced the upward slope of the graphs of Figure 3, the data constituting Figure 6 are fairly homogeneous and may be regarded as the best measure of the base-line drift of vertical magnetic field-balances available at present. It is interesting to note that the intercept of the curves of Figure 6 with the vertical coordinate-axis gives the average error of the mean of two simultaneous comparisons between two variometers. Its value, 0.9 gamma, is in good agreement with the precision with which field-observations can be repeated and checks the value obtained from another source by an independent calculation [Victor Vacquier, Short-time magnetic fluctuations of local character, Terr. Mag., v. 42, p. 22, 1937] when due allowance is made for the differences in the handling of the data.

Since Figure 6 expresses, on the average, the relative change between the base-lines of two Schmidt balances as a function of time, a measure of the average drift of the base-line of one instrument with respect to an observatory-standard is obtained by dividing the ordinates of Figure 6 by $\sqrt{2}$. Suppose that after comparison at an observatory a traverse is run with one Schmidt balance, terminating at the same observatory three months later. On the basis of a gaussian distribution, and according to the upper curve of Figure 6, the probability of incurring an error of closure greater than five gammas is one-half.

Although this value is small, it cannot justify the use of only one variometer because of the erratic behavior of individual instruments. In the prospecting work which furnished this figure, several instruments were constantly compared with one another so that the unsatisfactory operation of any one of them, which is usually accompanied by very rapid changes in base-line values, was immediately detected and remedied. To obtain the same performance a minimum of three instruments would be necessary in a survey of geodetic character; and it would be preferable to have four, so that if an accident should befall to any one instrument, three would be left to complete the traverse. In actual practice, instead of relying on a statistical estimate of precision like Figure 6, which is usually computed from other data, it would be preferable to estimate the magnitude and the direction of the drift of each instrument by mutual intercomparisons during the progress of the survey. For example, on Figure 4 the rise of 10.5 gammas shown by the curve 44-46 and the drop of 12 gammas of curve 46-5 between 3/36 and 4.5/36 can be largely attributed to instrument 46. Similarly, on the same Figure, the sudden rise of 12 gammas of curve 44-46 and the drop of 9.5 gammas of curve 46-5 between 2.5/37 and 4/37 is likewise due to instrument 46. Proceeding in this manner, one should be able to adjust the data so that the contribution of the zero-drift to the probable error of the determination of the vertical magnetic intensity at any station would be less than five gammas.

Another point worth mentioning is that, in the operations which furnished the above data, the equipment was subjected to much rougher usage and handling than would obtain in a survey of geodetic character. Such a survey is usually carried out on good roads; more time is available for observation; large temperature-gradients may be purposely avoided, and, as a consequence, better results could be obtained with very little effort.

I wish to thank Dr. E. A. Eckhardt for encouragement in the prosecution of this analysis and Dr. Paul D. Foote, Executive Vice-President of the Gulf Research and Development Company, for permission to publish this paper.

Gulf Research and Development Company,
Pittsburgh, Pennsylvania

# THE POSSIBILITY OF ELECTRICAL STRATIFICATION IN THE EARTH AS DISCLOSED BY SURFACE-MEASUREMENTS OF CURRENTS AND POTENTIALS

F. W. Lee
(Published with the approval of the Director, U. S. Geological Survey)

## Introduction

Early application of electricity to the ground was of interest particularly to telegraphy especially when it was first commercially applied. There was available at that time the Newtonian analysis of sources and sinks in a semi-infinite medium which could be applied directly to ground-contacts. Experiments conducted at that time showed that, while the electrical ground-resistivity was a factor, it was under engineering control. In computing the resistance of a ground-contact, Kennelly [see 1 of "References" at end of paper] equated the conducting surface buried in the ground to that of a hemisphere in a medium having a uniform resistivity, and the values so secured were within the safe limits of operation of telegraph- and cable-lines. Later Ollendorf [2] gave a very much more detailed solution of a large number of different types of ground-contacts for which was computed the current- and potential-distribution in the ground immediately around the ground-electrode. Wenner [3] also gave a classical solution for the measurement of ground-resistivity by using separate current- and potential-contacts to the ground which was good practice for measuring the resistivity of metal conductors.

## Anomalies in resistivity depth-relations from experimental sources

Later Rooney [4] and Gish [5] designed a commutating arrangement of ground-contacts in order to avoid troubles of polarization of the potential-electrodes. They measured the resistivity of large volumes of ground. While making such measurements Rooney observed certain discontinuities which occurred as the depth-effect was gradually increased and the depth of a fill was assigned to these abnormalities which showed in the shape of the resistivity-curves. Later such abnormalities were ascribed to irregularities of resistivity of the top of surface-layers of the ground which it was thought had materially modified the current-field distribution at the ground-surface. This was followed by a large amount of theoretical work by Hummel [6], Roman [7], Stefanesco and Schlumberger [8], and others using the Maxwell [9] image-method or Bessel functions for computing the field of current- and potential-distribution in the ground of bedded conductors. Observations made in northern Michigan and interpreted by Roman [10] confirmed the theoretical computations for computing the depth of the glacial drift in that region. At this time Swartz [11] made some measurements in Kentucky and found certain characteristics in the resistivity-depth relation which bore a definite relation to the geologic bedding of the gas- and oil-horizons and which occurred too often at the proper depths in different portions of the field to permit such anomalies to be accounted for by disturbances at the surface of the Earth. In order to eliminate factors such as surface-resistivity from other deep-seated changes Lee [12] introduced the partition-method. By this method a definite sequence in values of ground-resistivity measured in one direction should also occur in the opposite direction, often at different depths for each direction. Such coincidences eliminate any chance coincidence of ground-surface abnormalities. A typical curve is shown in Figure 1, where the same sequence exists for both directions but at different depths indicating a definite dip of the beds.

## Change of apparent resistivity with current-density

Earlier experiments made by Lee [13] showed very clearly that the apparent resistivity was not constant but changed with the density of the ground-current. Such a change is impossible in uniformly conducting beds, each having its own separate resistivity. Such observations were made sufficiently far away from current-stakes so as not to include polarization-phenomena at the contact-stakes with the ground. Later studies made on the Shoestring oil-areas of eastern Kansas exhibited a resistivity characteristic of the ground which was often found over a gas-producing area. Such a typical curve is shown in Figure 2 in which the notable characteristic is the very abrupt change of resistivity at a comparatively great depth. There was considerable difficulty in explaining such a very abrupt change upon pure resistance-changes of the beds. From well-logs the geology of this area was known to be stratigraphically very uniform and there was no abrupt change in or omission of beds.

## Effect of wet ground upon the resistivity

Further detailed studies were made concerning surface-anomalies which distort the resistivity-depth curves. It was found that surface-conditions of dry soil materially change the measured values as is shown by Figure 3 which was made before and after a rain. However, the deep-seated

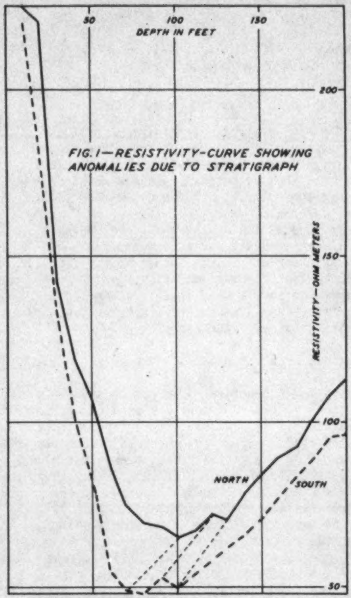


FIG. 1—RESISTIVITY-CURVE SHOWING ANOMALIES DUE TO STRATIGRAPH

anomalies can be discerned in both curves. It was experimentally determined that such deep-seated anomalies were to a certain degree independent of the spacing of the potential-contacts to the ground. It showed that surface-conditions screen deep-seated effects and that the depth of current-penetration was related to the spacing of the current-ground contacts. Figure 4 shows the same depth-anomalies observed for different potential electrode-spacings with observations made for separations of the current-electrodes varying from 150 to 600 feet.

### Suggestions of electrical double layer

Measurements were made upon abandoned shallow gas-pools in central Michigan to a depth of 1000 feet at stations located 1500 feet apart along three traverses separated by a mile. Upon charting resistivity-depth curves, it was discovered (see Fig. 5, A, B, C, and D) that certain characteristic sequences occur at the stations even when separated by large intervals or distances. It was possible to map a series of connected horizons (Fig. 6) in this area. Such characteristic features shown in Figure 5 were not equally clear on all portions of the curve but offered sufficient information to correlate the uncertain points with the better-defined ones.

A careful consideration of the possible causes of such abrupt breaks in the resistivity-depth curves indicates that they may be due to the presence of an electrical double layer. Helmholtz [14] has described electrical double layers,

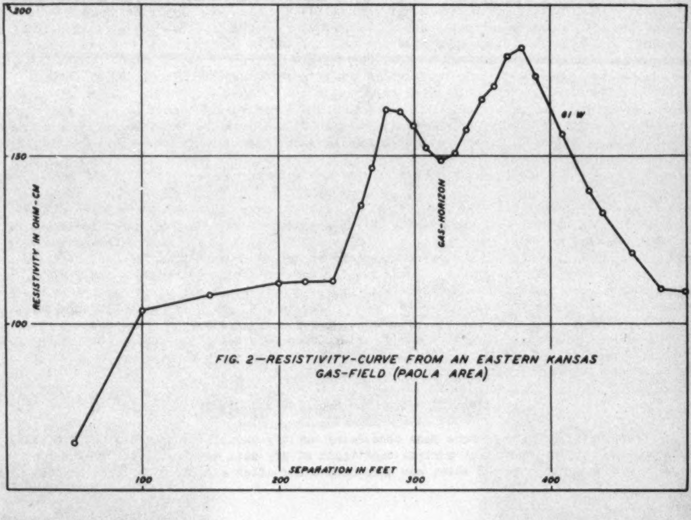


FIG. 2—RESISTIVITY-CURVE FROM AN EASTERN KANSAS GAS-FIELD (PAOLA AREA)

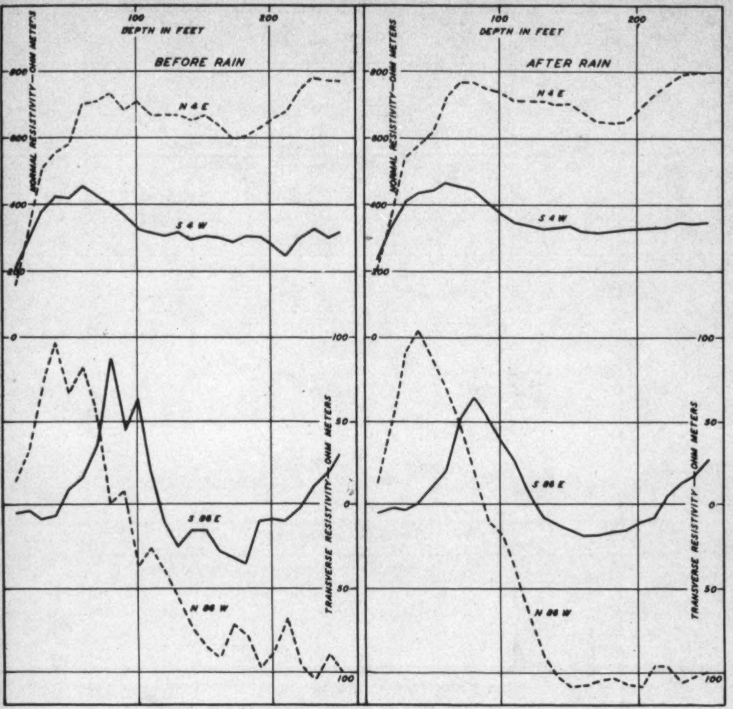


FIG. 3—CURVES SHOWING EFFECT OF RAIN ON RESISTIVITY

noting in particular the abrupt jump of potential when passing through it. Such an electrical double layer may have its origin at the contact of two dissimilar beds or may be due to adjacent solutions of different constitution or concentration in porous beds and at places where geochemical activity abounds. This charged layer is not exactly an idealized surface-distribution of electric charge which of necessity would make the potential infinite at the surface. It may be considered as a layer in which isolated ion-charges of the same polarity are spaced sufficiently near together to produce the effect of a charged surface.

Figure 7, part I, shows for purposes of illustration a contact between limestone and sandstone. The equivalent electrical configuration is shown in part II, consisting of material A having a resistivity $\rho_1$ and a material B having a resistivity $\rho_2$ with an electrical double layer between them. After the line-integral of electrical intensity at the interface has a voltage equal to that of the double layer, the current will break through it very abruptly and a new configuration of current-distribution in A and B will prevail. This introduces an abrupt change in the electrical resistivity-depth curves every time such a layer is broken down. There is a certain upper and lower limit of this condition in which the potentials across such layers may be high compared to other locations where it is low. Field-experience apparently indicates that artesian aquifers have very high potentials in certain localities across the double layers which control the phenomena of current- and potential-distribution in the ground, whereas in other locations, as, for example, in glaciated overburden, the reverse is the case.

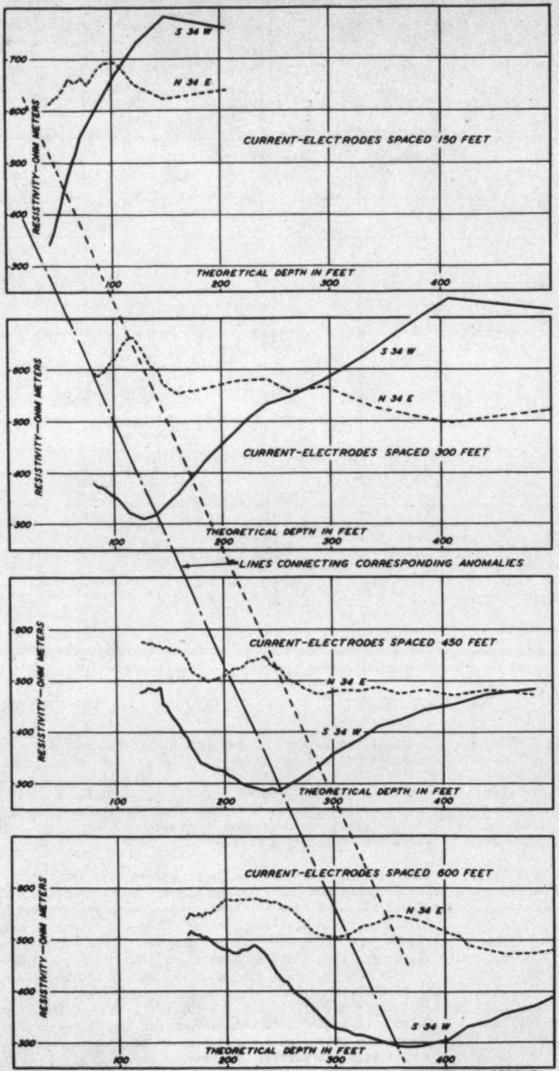


FIG. 4—ANOMALIES OF RESISTIVITY PLOTTED TO AGREE WITH THEORETICAL DEPTHS BASED ON THE NEWTONIAN FIELD

It was also observed that near churn-drilling operations there was a distinct change of current and potential when the drill struck the bottom of the hole. The impulse from the mechanical impact travels with different speeds in the two adjacent beds between which a double layer is present and mechanically breaks down or modifies the electrical equilibrium causing such changes of currents and potentials. For this reason it is often not possible to make resistivity-observations near churn-drilling operations. On the other hand, such methods may be useful in studying seismic waves from natural causes, especially earth-vibrations which precede more violent earthquakes.

Such double layers also materially modify the propagation of radio ground-waves especially where the double layer terminates at a fault, dike, or contact as was observed by Cloos [15]. There is a very large transfer of energy at those boundaries from the electrostatic field to the magnetic field or vice versa which may increase and damp out the waves at such boundary discontinuities.

## Summary

The above-described condition of electrical stratification will:

(a) Explain the abrupt change of the tangent to the resistivity-depth curve.
(b) Account for the seal over gas-beds as well as the abrupt changes in artesian aquifers.

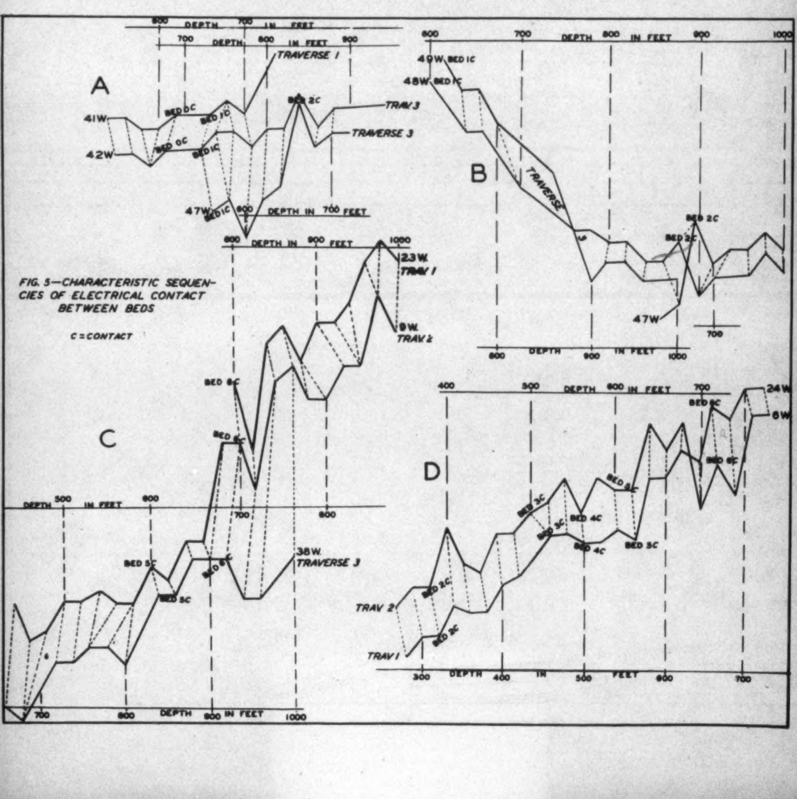
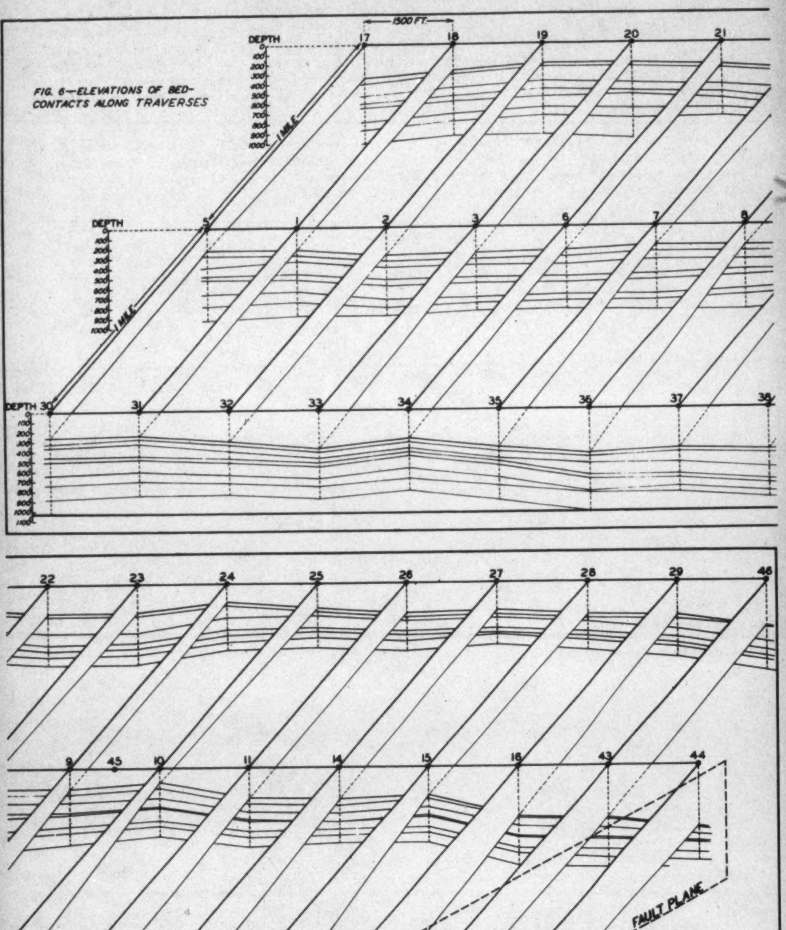


FIG. 5—CHARACTERISTIC SEQUENCIES OF ELECTRICAL CONTACT BETWEEN BEDS

C=CONTACT

FIG. 6—ELEVATIONS OF BED-CONTACTS ALONG TRAVERSES


1500 FT.
DEPTH
0
100
200
300
400
500
600
700
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900
1000
1100
1 MILE
17
18
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5
1
2
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7
8
30
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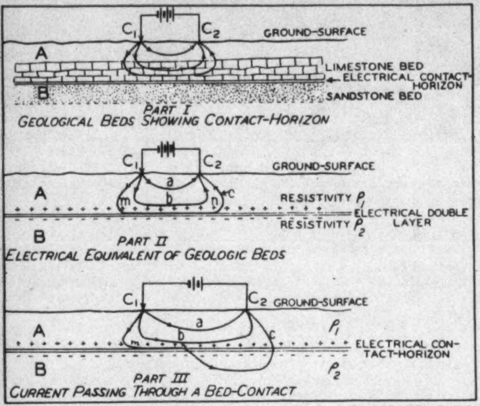
$C_1$
$C_2$
GROUND-SURFACE
A
LIMESTONE BED
ELECTRICAL CONTACT-HORIZON
B
SANDSTONE BED
PART I
GEOLOGICAL BEDS SHOWING CONTACT-HORIZON
$C_1$
$C_2$
GROUND-SURFACE
a
A
m
b
n
c
RESISTIVITY $\rho_1$
ELECTRICAL DOUBLE LAYER
RESISTIVITY $\rho_2$
B
PART II
ELECTRICAL EQUIVALENT OF GEOLOGIC BEDS
$C_1$
$C_2$
GROUND-SURFACE
A
a
b
c
m
$\rho_1$
ELECTRICAL CONTACT-HORIZON
B
$\rho_2$
PART III
CURRENT PASSING THROUGH A BED-CONTACT

FIG. 7—BED-CONTACTS AND ELECTRICAL DOUBLE LAYER BETWEEN THEM

(c) Show the characteristic of many bed-contacts.

(d) Permit the identification of buried anomalies by potential spacings which are not controlled by the Newtonian field-distribution.

In addition, it will alter customary thought in the following ways:

(a) The depth of current-penetration into the Earth under the old theory extended to infinity. Actually it is limited to the depth of such double layers. Increased depth-information may be possible only with greater distances between the current ground-contacts.

(b) Such layers associate themselves with rocks undergoing alterations and other geochemical activities.

(c) They greatly modify the flow of the current in the ground and form a working hypothesis for delineating geologic bodies.

(d) They cause the attenuation of radio ground-waves and the reflector- and refractor-characteristics observed at boundaries of geologic bodies.

(e) They permit a correlation between seismic impulses and variation of electric current-distribution.

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U. S. Geological Survey,
Washington, D. C.

## A SET OF SCALES AND CHARTS FOR EVALUATING ATTRACTION-COMPONENTS

Irwin Roman

(Published with the approval of the Director, U. S. Geological Survey)

### (Abstract)

If a point-source exerts a force according to the inverse-square law, the component of that force at a selected station, taken in a selected direction, may be computed by a simple formula. If the source is distributed, the law of distribution must be known. In some cases of distributed sources the exact value may be found by integration. However, in many cases, the integrations may not be possible in simple form, but a sufficiently accurate value may be obtained by dividing the source into small elements and treating each as a point-source.

If the source may be considered as equivalent to a set of laminas perpendicular to the direction in which the component is taken, the effects of the elements in a specific lamina may be measured graphically with a scale whose defining parameter is the distance from the station to the lamina. If the laminas are parallel to the component, the effects of the elements may be measured with a transparent chart whose defining parameter is the distance from the station to the specific lamina containing the elements.

A set of such scales and charts has been prepared. By their use, it is possible to evaluate the vertical component of the magnetic intensity due to a known magnetic body. Also, the component in any other direction may be found. It is possible to find the directed intensity of the gravitational field of a known mass or of the electric field for a known distribution of charge.

Details of the scales and charts are to be published later.

Section of Geophysics,
U. S. Geological Survey,
Baltimore, Maryland

## PROCEDURE AT MEETINGS OF THE INTERNATIONAL ASSOCIATION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

J. A. Fleming

At the triennial assemblies of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics the agenda include: National reports; reports of Committees and Reporters; scientific communications; joint discussions with other Associations on subjects of mutual interest; and adoption of resolutions concerning international cooperation and coordination of effort. The programs are arranged so that there may be no extensive overlapping with the meetings of the International Commission of Terrestrial Magnetism and Atmospheric Electricity of the International Meteorological Organization and in such a way as to coordinate in every possible manner the activities of these two bodies.

In view of the many reports and communications presented, it is not possible to read all of them, and therefore the effort is made to have, in so far as may be, reprints either in full or in abstract distributed before and at the meeting. Thus much more time is available for extended discussion of those subjects requiring world-wide cooperation and coordination. The Executive Committee of the Association selects certain communications, from the many papers submitted, for more or less complete presentation by the authors.

All communications and minutes are printed in full in the Bulletin of the Association containing the Transactions for each meeting. Other numbers of the Bulletin are published from time to time when special reports are made. So far, ten Bulletins have been issued; any of these may be obtained from the Secretary and Director of the Central Bureau of the Association (at present, Dr. A. H. R. Goldie, Meteorological Office, Air Ministry, Adastral House, Kingsway, London, W.C. 2, England.)

Besides the Bulletin, the Association provides funds for publication, through the good offices of the Royal Meteorological Institute of the Netherlands, of two series on magnetic character, namely, "Caractère magnétique de chaque jour" (quarterly since 1906) and "Caractère magnétique numérique des jours" (28 parts since 1932 and covering period from January 1930). These publications include, from time to time, supplemental parts; among these, for example, is

"Supplément, Caractère magnétique numérique des jours pendant l'Année Polaire Internationale 1932-1933." Some assistance is also given from time to time for special publications such as the "Auroral atlas," etc.

The funds available do not permit subsidizing of individual researches except in rare cases when they are of so distinctly international character that funds may not be made available from national or private sources. Thus at Edinburgh small grants were made available to assist in special investigations of giant pulsations in Iceland, to promote international comparisons of magnetic standards, and compilations bearing on the Moon's effect upon magnetic variations.

The activities of the Association may be well summarized by enumerating its present Committees and Reporters. The Committees are: On selection of sites of new observatories for terrestrial magnetism and electricity (this Committee has in preparation a list of magnetic observatories and values); Auroral Committee; On the study of the relationship between solar activity and terrestrial magnetism; On magnetic secular-variation stations; On the study of electrical characterization of days; On magnetic charts, including (1) Organization of the work and (2) Methodology; On registration in Iceland of giant pulsations; On methods of observatory-publication; On classification of magnetic literature; To promote international comparisons of magnetic standards; Joint Committee of the Commission of Terrestrial Magnetism and Atmospheric Electricity and of the Association on methods and codes to adequately describe magnetic disturbances and perturbations; Joint Committee of the Association and of the International Scientific Radio Union. The subjects for which special Reporters are named include: On numerical magnetic characterization of days; On international collaboration for promoting the study of the influence of the Moon on geophysical phenomena; On ion-counters.

During the interims between meetings the Secretary and Director of the Central Bureau is the executive officer acting through the Executive Committee consisting of the President, the two Vice-Presidents, the Secretary, and five members (all elected at General Assemblies of the Association).

In conclusion, the objects of the Association are epitomized, as indicated in its Statutes, as follows:

"(1) The study of questions relating to terrestrial magnetism and electricity in so far as these questions require international cooperation for their effective investigation.

"(2) The encouragement of research in the above subjects by individual countries, institutions, or persons."

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

## THE SPRENGNETHER STUDENT MAGNETOMETER

James B. Macelwane

This paper was presented informally and no manuscript was submitted.

St. Louis University,
St. Louis, Missouri

## EQUIPMENT FOR TESTING SOUNDING-BALLOON INSTRUMENTS AT LOW TEMPERATURE AND PRESSURE

Brian O'Brien

No manuscript or abstract of this paper was submitted.

University of Rochester,
Rochester, New York

# REPORTS ON MAGNETIC AND ELECTRIC WORK OF ORGANIZATIONS IN NORTH AMERICA DURING 1938-39

## MAGNETIC WORK OF THE UNITED STATES COAST AND GEODETIC SURVEY, APRIL 1938 TO MARCH 1939

N. H. Heck

Magnetic surveys--Magnetic observers were assigned to five triangulation-parties to make compass-declinometer observations at triangulation-stations. This was a new procedure. As a result, declination was obtained at 810 new stations in Alabama, Arizona, Arkansas, California, Illinois, Iowa, Kansas, Louisiana, Minnesota, Mississippi, Missouri, New Mexico, New York, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Dakota, Utah, and Wyoming. The Bureau's regular personnel determined declination at 146 other stations in Alaska and 19 States. Complete observations for declination, horizontal intensity, and dip were made at 28 stations in Alaska, California, Florida, Georgia, Kansas, Michigan, Minnesota, Missouri, Montana, Nevada, North Carolina, North Dakota, Ohio, South Carolina, Tennessee, Utah, Washington, and Wyoming. Thus magnetic observations were made in all but eight States, namely, Connecticut, Delaware, Idaho, Indiana, New Hampshire, New Jersey, Rhode Island, and West Virginia.

Magnetic observatories and cooperative work--The five magnetic observatories of the Bureau have been maintained in continuous operation. At Tucson an auxiliary absolute building, for the purpose of making intercomparison of instruments, has been built. The variation-building was found to be so damaged by dry-rot and termites as to be unsafe and provision has been made for the erection of a new building at another site. At Sitka, Alaska, new construction in the vicinity of the Observatory has come so close as to disturb the proper functioning of the instruments, and transfer to another site is in contemplation.

At Honolulu a la Cour vertical-intensity variometer has been substituted for one of less satisfactory performance. The improvement of the absolute instruments in use at Puerto Rico is in progress in the Washington Office.

Through cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, the following listed projects have continued:

(a) Use of sine-galvanometer and standard earth-inductor of the Carnegie Institution of Washington at Cheltenham was continued. The National Bureau of Standards has compared the standard cells of the sine-galvanometer during the year.
(b) The cosmic-ray meter at Cheltenham for the Committee on Coordination of Cosmic-Ray Investigation of the Carnegie Institution of Washington was operated throughout the year.
(c) Standardization of field-instruments used by the Carnegie Institution of Washington was made by their own personnel at Cheltenham.
(d) Continuation of operation of perminvar vertical-intensity variometer at Cheltenham on an experimental basis.
(e) Continuation of atmospheric-electric and earth-current programs at the Tucson Magnetic Observatory.
(f) Contribution to broadcast and publication of daily magnetic data [see Trans. Amer. Geophys. Union, 1938, Part I, p. 219] was continued.

Special investigations--(a) As a result of the successful test of the quartz horizontal magnetometer (QHM) loaned by D. la Cour, results of which are described in last year's report, a set of QHM's was purchased, compared at Cheltenham Observatory, and successfully used in field-work in the southeastern part of the United States.
(b) A transit-magnetometer was developed to replace the compass-declinometer, the essential change relating to magnetic declination being the substitution of a telescope for peep-sights. It has been found possible to get good results of H [see report of H. E. McComb and J. W. Joyce in these Transactions, pp. 364-366].
(c) Progress was made in the development of a portable magnetic observatory, but it has not been possible to put it into field-use. A suitable tent is now available.
(d) There has been further development in the method of testing marine compasses at Cheltenham for use in determining magnetic declination at sea.

Work on records--"Results of magnetic observations at Tucson Magnetic Observatory, 1929-30" was issued. Work was discontinued on the regular series in order to complete the information for the period for the Second Polar-Year, August 1932 to August 1933. Results at the Cheltenham

Observatory for the Polar Year have been completed and steady progress is being made on the work for College-Fairbanks and all the other observatories except San Juan, Puerto Rico. The Works Progress Administration Computing Office in New York, with D. G. Knapp of the United States Coast and Geodetic Survey in immediate charge of the magnetic work, is engaged in this work, and also in completing the results of field-observations made through the expenditure of Works Progress Administration funds.

It is of interest that the Maritime Commission has found the publication "Instructions for compensation of the magnetic compass" of great value in training marine officers and that a steady demand from International sources continues for the publication "Directions for magnetic measurements."

U. S. Coast and Geodetic Survey,
Washington, D. C.

## IONOSPHERE RESEARCHES OF THE NATIONAL BUREAU OF STANDARDS DURING 1938

S. S. Kirby

Regular measurements, both automatic and manual, of critical frequencies and virtual heights of the layers of the ionosphere were continued, for frequencies from 600 to 16,000 kc/sec. The regular publication of these data maintained unbroken the continuity of published ionosphere data since 1933, thus covering the ascending half of one solar cycle. This continuity is important in studying the characteristic regular and irregular variations of the ionosphere, diurnally, seasonally, and year to year with the sunspot-cycle. The vertical-incidence ionosphere measurements were supplemented by oblique-incidence radio field-intensity records of stations on frequencies ranging from 550 to 30,000 kc/sec.

The regular dissemination of information on ionosphere and radio-transmission conditions was continued, employing weekly Ursigrams, weekly radio broadcasts from the Bureau's station WWV, monthly ionosphere reports in the Proceedings of the Institute of Radio Engineers, quarterly reports in the Journal of Terrestrial Magnetism and Atmospheric Electricity, and additional published papers on various topics. The monthly reports in the Proceedings of the Institute of Radio Engineers give the following data regularly: (1) Graphs of monthly average diurnal variations of critical frequencies and virtual heights; (2) graphs of monthly average diurnal variations of maximum usable frequencies for radio sky-wave transmission the preceding month and predicted values for the second month in advance; (3) graph showing day-to-day distribution of critical frequency around the monthly average; (4) tables of ionosphere storms, sudden ionosphere disturbances, and, in the summer, sporadic E. The predicted values under (2) are estimated from a knowledge of the diurnal and seasonal variations and the trend of the critical frequencies with the sunspot-cycle.

During 1938 the sunspot-cycle, and with it the critical frequencies and ionization-densities of the ionosphere layers, began a steady decrease from the maximum. The observed ratios of the maximum to the minimum ionization-densities during the sunspot-cycle were as follows: (1) Night F-layer and daytime $F_2$-layer, 4 to 1; daytime $F_1$, 2 to 1; daytime E, 1.5 to 1. The number and severity of sudden ionosphere disturbances were also markedly less in 1938 than in 1937, corresponding to decreased solar activity. The prolonged periods of low-layer absorption first reported in 1937 were also much less in evidence in 1938. During the first half of 1938 the most severe ionosphere storms of the present sunspot-cycle were observed. The severity and frequency of ionosphere storms diminished during the latter half of 1938 and the first quarter of 1939.

The Bureau's observations of ionosphere storms during 1938, together with those of previous years, led to the formulation of a comprehensive view of the nature of these storms. The ionosphere storm has two phases. The first or turbulent phase consists of a violent turbulence or boiling of the entire ionosphere in the auroral zone resulting in the destruction of the normal stratification of the ionosphere from the E-layer on up. This phase is preceded by a sudden unstable increase of ionization of the F- or $F_2$-layer, and is followed by the second or moderate phase, characterized by the expansion and diffusion of the higher F- or $F_2$-region at latitudes not only in, but also fairly well removed from, the auroral zone. After the ionosphere storm ends in the upper ionosphere there remains for several days a residual ionization below the E-layer which is manifested by marked absorption of broadcast frequencies at night.

The Bureau's automatic recording of field-intensities of European and South American broadcast stations during the winter of 1938-1939 confirmed the existence of the anomaly reported in previous years between broadcast transmission over the North Atlantic and over more southerly paths. This is apparently due to greater severity and frequency of ionosphere storms over the North Atlantic path because of its proximity to the auroral zone.

Continuous automatic radio field-intensity records from a high-frequency station at oblique incidence indicated that the much-discussed Lorentz polarization-term should not be included in the theory of radio transmission by way of the E-layer.

Further theoretical work on the relation between vertical and oblique-incidence ionosphere transmission was published, including the effects of the curvature of the Earth and the ionosphere.

The following papers were published:

T. R. Gilliland, S. S. Kirby, and N. Smith, Characteristics of the ionosphere at Washington, D. C., published monthly in Proc. Inst. R. Eng. for the second month before.

Averages of critical frequencies and virtual heights of the ionosphere, observed by the National Bureau of Standards, Washington, D. C., published quarterly in Terr. Mag.

N. Smith, Application of vertical-incidence ionosphere measurements to oblique-incidence radio transmission, J. Res. Nation. Bur. Stan., v. 20, p. 683, 1938.

T. R. Gilliland, S. S. Kirby, N. Smith, and S. E. Reymer, Maximum usable frequencies for radio sky-wave transmission 1933-1937, J. Res. Nation. Bur. Stan., v. 20, p. 627, 1938, and Proc. Inst. R. Eng., v. 26, p. 1347, 1938.

S. S. Kirby, N. Smith, and T. R. Gilliland, The nature of the ionosphere storm, Phys. Rev., v. 54, p. 234, 1938.

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National Bureau of Standards,
Washington, D. C.

## MAGNETIC WORK OF THE NATIONAL ASTRONOMICAL OBSERVATORY OF THE NATIONAL UNIVERSITY OF MEXICO

Joaquin Gallo

The magnetic activities of the National University of Mexico last year included only that at the Teoloyucan Magnetic Observatory and some computational work, because the funds available to the University did not permit any field-work.

The program of secular-variation observations is now being conducted. One of our observers left for Guaymas and Mazatlan March 13, 1939, to reoccupy the magnetic stations there. It is hoped that by next fall observations will be obtained at Tampico and Monterrey.

National Astronomical Observatory,
Tacubaya, D.F., Mexico

## PROGRESS-REPORT ON RESEARCHES IN TERRESTRIAL MAGNETISM AND ELECTRICITY AT DEPARTMENT OF TERRESTRIAL MAGNETISM, CARNEGIE INSTITUTION OF WASHINGTON, FOR YEAR APRIL 1938 TO MARCH 1939

J. A. Fleming

The energetic prosecution of experimental investigation and the reduction and interpretation of results obtained, making for a clearer understanding of the nature of geophysical phenomena, have characterized the activities of the Department during the year. In the execution of such research, it is essential from time to time to present a picture of the exact status of progress achieved. In this regard the Department has had a large share in the production of two treatises of the highest importance to the sciences of terrestrial magnetism and electricity which will satisfy a long-felt need in the literature of geophysics. "Geomagnetism" by J. Bartels and S. Chapman will soon be issued by the Oxford University Press, and "Terrestrial Magnetism and Electricity," being volume VIII of the Physics of the Earth series sponsored by the National Research

Council, is being printed by the McGraw-Hill Book Company, and will issue in August, 1939. The former presenting the theoretical elements and the latter the practical and descriptive aspects will supplement each other in an authentic exposition of the subjects.

Magnetic investigations--The principal advances in the study of terrestrial magnetism during the period under consideration are associated with phenomena of the Earth's field which have their origin beneath the Earth's surface and consequently are connected intimately with the problem of the cause and origin of the general magnetic field of the Earth.

The problem of secular variation has been attacked through the study of paleomagnetization of rocks. Significant results have been obtained from measurements of the magnetization of the varved Pleistocene clays left by the retreat of the last glaciation from New England. These measurements of sediments covering a period of 1000 years in glacial times indicate that the secular variation in glacial times was progressing at a rate similar to that disclosed by actual measurements in historic times.

Isoporic charts were constructed for the north and east components of secular change for the epoch 1920-1925, using Fisk's data. Tests were developed for assisting in estimating the accuracy of isoporic maps of the Earth, using line-integrals of the field of the magnetic secular variation. An approximate derivation of a world-wide representation of secular change was obtained by an equivalent isoporic magnetic shell just beneath the Earth's surface. The dissipation of energy from the Earth caused by the field of secular variation was found to be relatively much smaller than in the cases of other sources of dissipation of energy within the Earth.

Research has also been undertaken on the relation of terrestrial magnetism to geological conditions. To test the effectivensss of magnetic methods as an approach to volcanological problems, the Department of Terrestrial Magnetism, in cooperation with the Geophysical Laboratory, made a magnetic survey of the region about the volcano Santa Maria in Guatemala. The results obtained prove the practicability of the method. Variations in the vertical intensity of the magnetic field, amounting to 15 per cent of the total vertical intensity, showed high correlation with known structural features of the region.

Records of the severe magnetic storms of 1938 from various observatories all over the world have been collected and their effects are being analyzed.

Good progress is being made in a new analysis of the daily magnetic variations. This work is being extended to the analysis of magnetic-storm data, special attention being given to the relation between the external and internal parts of the field.

The derivation of the seasonal average characteristics of the disturbance daily variation and daily means of disturbance was continued, using the international disturbed days of the International Polar Year, 1932-1933, for various stations.

An investigation was made of the world-wide disturbance fields of individual magnetic storms, using extensive data for four storms of the International Polar Year, 1932-1933. Mean hourly disturbance-vectors were derived for about 48 hours of each storm. The field-characteristics found for each hour of storm showed good general agreement with the previous findings of Birkeland. The main systematic mean hourly characteristics of the field were also shown to be in rough general agreement with those deduced from average characteristics of the field. Evidence was also found of important seasonal changes in the general form of the field, particularly in the polar regions. Although there is some possibility that a part of the electric currents responsible for magnetic storms flows outside the Earth's atmosphere, useful derivations were obtained of the form and intensity of these currents for the case when the currents are assumed to flow within the atmosphere. The mean hourly current-systems showed good agreement in general type with those proposed by Chapman.

Studies of the world-wide disturbance-fields of magnetic bays were continued and an investigation was made to determine whether the $S_D$ current-system of magnetic storms suggested by Chapman could arise from electromotive forces generated mainly along the auroral zone. An investigation is also under way to develop a more convenient method than the standard procedure of spherical harmonic analysis for analyzing the disturbance-field of storms and the secular variation.

Instruments--Good progress has been made on the new CIW electromagnetic standard. The actual coils, both primary and secondary, have been completed. The secondary dimensions have been measured, and the measurements on the primary are in progress. It is estimated that the new standard will be in operation at the beginning of 1940. The theory of the new primary standard was developed as published.

Geoelectric investigations--Quantitative analysis of ionospheric changes is now possible and was begun upon completion of the automatic multifrequency apparatus recently put into operation. Such quantitative analysis must eventually make possible the description of fluctuations in the ionosphere of ion-density, height, and conductivity in mathematical expressions as functions of the factors controlling them.

Intercomparisons of simultaneous values of ion-density in the highest region ($F_2$-region) of the ionosphere between Watheroo and Canberra show that very large fluctuations occur which cannot be explained simply on the basis of uniform ionizing radiation. This discovery introduces a new factor into ionospheric investigation and demonstrates that, except on the average, observations from one station are not representative of more than a certain limited area as regards the important $F_2$-region.

A new phenomenon has been discovered. About two hours before sunrise a bank of ions of density about 10,000 electrons per cc moves downward from the 250-km level, coming to rest at about 140 km in about an hour and decreasing in ion-density because of recombination. Such movements and separation of ion-banks in absence of direct sunlight open a new field for theoretical work on physics of the upper atmosphere.

Good progress was made during the year on the preparation for publication of the atmospheric-electric data obtained since 1924 at the Watheroo and Huancayo observatories. These data for the years 1924-1934 are now in satisfactory form for detailed investigation and discussion.

Investigation has shown that the large quantities of smoke which are prevalent at Watheroo during December to March, noticeably increasing the potential-gradient and reducing the conductivity, leave no effect on the air-earth current. At Huancayo, the number of days on which rain falls per month greatly influence the air-earth current through the effect on concentration and distribution of condensation-nuclei in the air. It is concluded that the condensation-nuclei are distributed to considerable heights at Huancayo during the dry months, but that in the wet months they are washed out of the air and kept at low concentrations by the repeated rains.

During March and April, 1939, a continuous registration of the two components of the electrical potential-gradient in the Earth was made on the flank of the volcano Santa Maria in Guatemala, and surveys were made of earth-potentials at other points about the volcano. Interpretation of these data is now in progress.

Observatory-work--The observatories at Huancayo, Peru, and Watheroo, Western Australia, continued their extensive program of geophysical observations, obtaining continuous records of the magnetic elements.

Cooperative work was continued with the following observatories: Atmospheric-electric program at Apia in Western Samoa; atmospheric-electric and earth-current programs at Tucson, Arizona; maintenance of international magnetic standards at the Cheltenham Magnetic Observatory of the United States Coast and Geodetic Survey. Cooperation was also extended to the Director of the British East African Meteorological Service through the loan of a magnetometer-inductor.

Land-work--A magnetic survey was conducted in the region around the volcano Santa Maria in Guatemala during the period January to March, 1939. Vertical intensity was observed with Askania field-balances at 449 individual stations, at 50 of which declination was observed with a regular CIW magnetometer and horizontal intensity with a QHM instrument. Close to the volcano the stations were spaced about 500 meters apart while at greater distances the station-spacing was increased gradually up to a maximum of 3000 meters.

Publications--The activities of the Department are set forth in greater detail in the Year Book of the Carnegie Institution. A few of the papers published during the last year are listed below.

J. Bartels, Berechnung der lunaren atmosphärischen Gezeiten aus Terminablesungen am Barometer, Beitr. Geophysik, v. 54, pp. 56-75, 1938.

J. Bartels, Harmonic analysis of diurnal variations for simple days, Terr. Mag., v. 44, pp. 137-156, 1939.

J. Bartels, Besprechung erdmagnetischer Registrierungen im Hinblick auf Vorgänge in der Ionosphäre und Wirkungen in der Höhenstrahlung, Zs. Geophysik, v. 14, pp. 297-313, 1938.

L. V. Berkner, Concerning the nature of radio fade-outs, Phys. Rev., v. 55, pp. 536-544, 1939.

L. V. Berkner and A. G. McNish, The ephemeral variations of the Earth's magnetism, Carnegie Inst. Wash., Pub. No. 501, pp. 223-247, 1938.

H. G. Booker, Propagation of wave-packets incident obliquely upon a stratified doubly refracting ionosphere, Phil. Trans. R. Soc., v. 237, pp. 411-451, 1938.

H. G. Booker and L. V. Berkner, An ionospheric investigation concerning the Lorentz polarization-correction, Terr. Mag., v. 43, pp. 427-450, 1938.

H. G. Booker and H. W. Wells, Scattering of radio waves by the F-region of the ionosphere, Terr. Mag., v. 43, pp. 249-256, 1938.

S. Chapman, The atmospheric height-distribution of band-absorbed solar radiation, Proc. Phys. Soc., v. 51, pp. 93-109, 1939.

B. Cynk, Variations in the disturbance-field of magnetic storms, Terr. Mag., v. 44, pp. 51-57, 1939.

J. A. Fleming, The general magnetic field of the Earth and its secular variation, Carnegie Inst. Wash., Pub. No. 501, pp. 205-221, 1938.

J. A. Fleming and O. H. Gish, Annual report of the Director of the Department of Terrestrial Magnetism, Carnegie Inst. Wash., Year Book No. 37, pp. 239-293, 1938.

S. E. Forbush, On world-wide changes in cosmic-ray intensity, Phys. Rev., v. 54, pp. 975-988, 1938.

S. E. Forbush, On cosmic-ray effects associated with magnetic storms, Terr. Mag., v. 43, pp. 203-218, 1938.

O. H. Gish, Universal aspects of atmospheric electricity, Carnegie Inst. Wash., Pub. No. 501, pp. 183-204, 1938.

O. H. Gish and H. G. Booker, Non-existence of continuous intense ionization in the troposphere and lower atmosphere, Proc. Inst. Radio Eng., v. 27, pp. 117-125, 1939.

E. A. Johnson, Limiting sensitivity of an alternating-current method of measuring small magnetic moments, Rev. Sci. Instr., v. 9, pp. 263-266, 1938.

E. A. Johnson, A primary standard for measuring the Earth's magnetic vector. I--Theory, Terr. Mag., v. 44, pp. 29-42, 1939.

T. H. Johnson, Cosmic-ray intensity and geomagnetic effects, Rev. Modern Phys., v. 10, pp. 193-244, 1938.

T. H. Johnson, Recent advances in the investigation of cosmic rays, J. Wash. Acad. Sci., v. 29, pp. 233-256, 1939.

A. G. McNish and E. A. Johnson, Magnetization of unmetamorphosed varves and marine sediments, Terr. Mag., v. 43, pp. 401-407, 1938.

O. W. Torreson, Condensation-nuclei in the atmosphere at the Huancayo Magnetic Observatory, Peru, and their relation to atmospheric-electric and meteorological observations, Terr. Mag., v. 44, pp. 59-74, 1939.

M. A. Tuve, The forces which govern the atomic nucleus, Sci. Mon., v. 47, pp. 344-363, 1938.

E. H. Vestine, Asymmetrical characteristics of the Earth's magnetic disturbance-field, Terr. Mag., v. 43, pp. 261-282, 1938.

E. H. Vestine and S. Chapman, The electric current-system of geomagnetic disturbance, Terr. Mag., v. 43, pp. 351-382, 1938.

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AMERICAN GEOPHYSICAL UNION

Twentieth Annual Meeting

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Washington, D. C.
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# OCEANOGRAPHIC ACTIVITIES OF THE HYDROGRAPHIC OFFICE AND THE UNITED STATES NAVY DURING 1938

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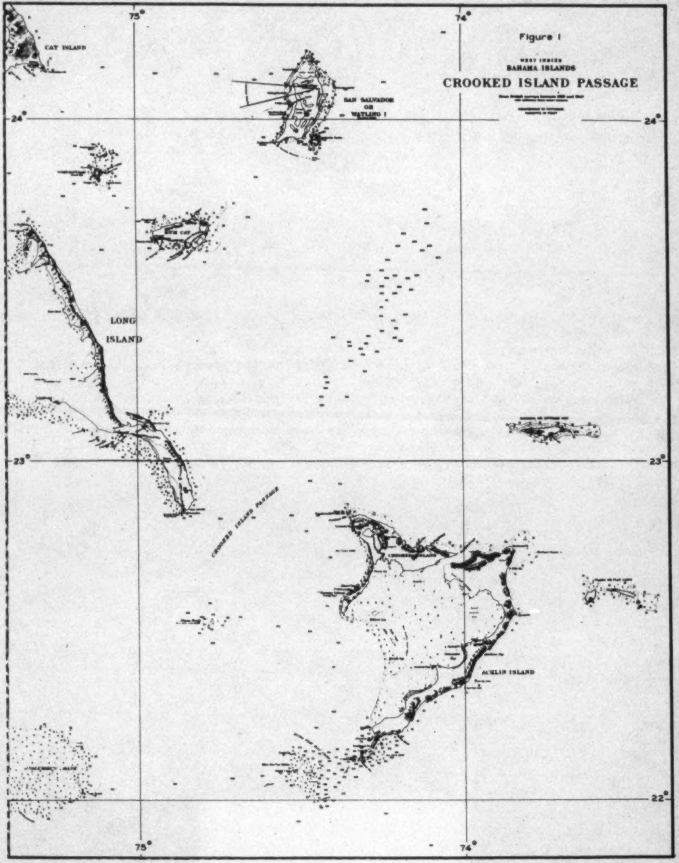
In accordance with its policy of contributing to the advancement of oceanography whenever possible, the Hydrographic Office of the United States Navy, in connection with its regular activities, during 1938, has collected much data of value to oceanographers and scientists in general.

During 1938 practically every unit of the United States Navy, equipped with sonic depth-finding apparatus, has done its part towards increasing the existing knowledge of submarine topography by obtaining sonic soundings while traversing areas previously unsounded whenever the opportunity permitted.


75°
74°
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23°
22°
WEST INDIES
BAHAMA ISLANDS
CROOKED ISLAND PASSAGE
CAT ISLAND
SAN SALVADOR OR WATLING I
RUM CAY
LONG ISLAND
CROOKED ISLAND PASSAGE
ACKLIN ISLAND

Figure 1

Cruises across the North and South Pacific, the North and South Atlantic, and in the Caribbean Sea, have, in the past 12 months, yielded over 46,000 sonic soundings, exclusive of those obtained by regular naval survey-vessels. The U.S.S. Ramapo alone, in six passages, made 6804 soundings across the North Pacific, which, combined with those previously obtained in this area, make a total of 35,976 soundings obtained in 50 crossings.

An examination of the sonic soundings obtained by naval vessels reveals that to obtain such a wealth of information, the observing vessels had to depart from their regular routes in order that the maximum benefit in the matter of new hydrographic information could be derived from each cruise. Only with the full cooperation of the United States Navy Department and the commanding officers of these naval vessels was this possible, and mariners and scientists alike have profited from the resultant data that have come to the Hydrographic Office.

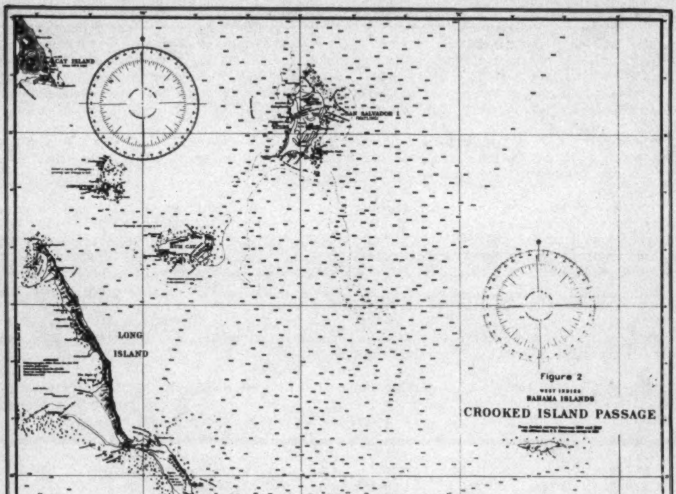

CAY ISLAND
SAN SALVADOR I
RUM CAY
LONG ISLAND
CROOKED ISLAND PASSAGE
WEST INDIES
BAHAMA ISLANDS
CROOKED ISLAND PASSAGE
ACKLIN ISLAND

Figure 2

To better illustrate the value of such cooperation, there is shown an early edition of the chart of Crooked Island Passage, based on original British surveys (Fig. 1), and also a copy of the latest edition of the same Hydrographic Office chart of this Area (Fig. 2), to which has been added a comprehensive selection of the thousands of sonic soundings obtained by United States Naval vessels while passing through this important Passage during the past few years. In the first edition only the inshore hydrography is portrayed, for in those days to sound the deep-water area would have been a long and costly undertaking. It will be observed that today a considerable knowledge of the submarine topography has been determined, information which is of great value while making passage at night or during adverse weather-conditions. The geologist will be interested in visualizing the submarine configuration and its relation to the land-masses. The seismologist and the oceanographer can, with the more complete data at hand, carry out their work to greater advantage.

It will be of interest to note that in the continuation of this program for the year 1939, the U.S.S. *Milwaukee*, while steaming westward through Brownson Deep in the Puerto Rican Trough, discovered at two slightly separated points, the greatest depth yet recorded in the North Atlantic Ocean. In latitude 19° 36' 00" north, longitude 68° 20' 30" west, and also in latitude 19° 35' 00" north, longitude 68° 08' 45" west, identical fathometer-soundings of 4780 fathoms were obtained. The fathometer of the *Milwaukee* is calibrated for 4800 feet per second and the above soundings are not corrected for temperature, density, or salinity.

This spot, for which this office suggests the name "Milwaukee Depth," is about 30 miles to the westward of "Dolphin Depth," the previous record sounding in the North Atlantic, the latter having been discovered in 1902 by the U.S.S. *Dolphin*.

To those who pioneered in the development of the transmission of sound through water and who have perfected an instrument of precision for determining depth with accuracy combined with rapidity, the mariner and the scientist owe a debt of gratitude. When the first sonic sounding apparatus was installed in Naval vessels during 1922, hydrography was given a fresh impetus, with a new field to conquer, vast in extent. The Navy Department and the Hydrographic Office have done, and will continue to do, their share in bringing to light the many heretofore unfathomed mysteries which still lie beneath the surface of the seas.

The following is a tabulated list of echo (sonic) soundings obtained by United States Naval vessels from January 1, 1938, to December 31, 1938:

U.S.S. *Hannibal* - 1493 sonic soundings obtained on 13 trips en route Port of Spain, Trinidad, British West Indies, to Boca Grande Bar, Orinoco River, Venezuela, and return from approximate 10° 46'.5 north in 61° 37' west to approximate 9° 15'.5 north in 60° 31'.5 west.

U.S.S. *Vega* - 50 sonic soundings obtained off west coast of California, extending from 28° 21'.4 north in 115° 49' west to 27° 10'.1 north in 115° 33'.4 west.

U.S.S. *Bridge* - 77 sonic soundings obtained on passage from Pearl Harbor, Territory of Hawaii, to Shanghai, China, crossing 23° 40' north in 171° 34' west and 31° 05' north in 136° 37' east.

U.S.S. *Reid* - 159 sonic soundings obtained off San Diego, California, crossing 32° 37' 14" north in 117° 14' 42" west, and 31° 30' north in 129° 15' west.

U.S.S. *Chaumont* - 632 sonic soundings obtained en route Cape Engano, Philippine Islands, to Kauia Rock, Territory of Hawaii, crossing 19° 17'.5 north in 123° 43' east; 25° 28' north in 172° 42'.5 east and crossing 22° 36'.5 north in 165° 46'.5 west.

U.S.S. *Vincennes* - 171 sonic soundings en route Balboa, Canal Zone, to Los Angeles, California, crossing 7° 45' north in 82° 55' west, 15° 15' north in 97° 37' west, 22° 20' north in 109° 47' west, and crossing 31° 06' north in 116° 52' west.

U.S.S. *Brooklyn* - 700 sonic soundings obtained in the Caribbean and North Atlantic, crossing 19° 52' 07" north in 74° 50' 30" west, 19° 39' 20" north in 77° 58' 00" west, 20° 19' 20" north in 81° 45' 30" west, 22° 25' 00" north in 85° 48' 00" west, and 29° 12' 45" north in 94° 32' 00" west.

U.S.S. *Rathburne* - 55 sonic soundings obtained southwest of Oahu, Territory of Hawaii, 21° 20' 00" north in 158° 10' 00" west.

U.S.S. *Case* - 390 sonic soundings obtained en route Norfolk, Virginia, to San Diego, California, via Panama Canal, and crossing 24° 02' 45" north in 74° 16' 00" west, 16° 06' 15" north in 76° 57' 00" west, 12° 42' 30" north in 78° 33' 30" west, 9° 22' 15" north in 87° 12' 00" west, and 26° 04' 45" north in 114° 07' 15" west.

U.S.S. *Fanning* - 1402 sonic soundings obtained in the Caribbean Sea crossing 18° 44' 00" north in 63° 33' 20" west, 15° 08' 00" north in 60° 25' 00" west, 13° 18' 00" north in 59° 40' 30" west, 14° 06' 00" north in 69° 45' 00" west, 17° 25'10" north in 77° 17' 50" west, and 20° 17' 00" north in 71° 12' 00" west.

U.S.S. *Philadelphia* - 1281 sonic soundings obtained in the Caribbean Sea crossing 19° 56' 07" north in 74° 17' 30" west, 20° 16' 00" north in 71° 40' 22" west, 15° 08' 30" north in 60° 18' 00" west, 13° 04' 00" north in 59° 43' 42" west, 12° 37' 00" north in 69° 14' 30" west, 16° 05' 00" north in 71° 09' 00" west, and 17° 45' 30" north in 76° 30' 00" west.

U.S.S. *Erie* - 573 sonic soundings in the Atlantic and the Caribbean Sea, crossing 24° 00' north in 74° 19' west, 21° 50' 00" north in 74° 33' west, 20° 28' 00" north in 74° 00' 00" west, 17° 48' 00" north in 75° 05' 00" west, 15° 00' 00" north in 77° 20' 00" west, and 9° 38' 00" north in 79° 52' 00" west.

U.S.S. *Vega* - 18 sonic soundings obtained in vicinity of Morgan Bank, off Lower California, 22° 57' 00" north in 110° 10' 30" west.

U.S.S. *Trenton* - 55 sonic soundings obtained in unsounded areas in China Sea, crossing 11° 50' 00" north in 113° 40' east, and crossing 11° 39' 18" north in 119° 01' 18" east.

U.S.S. *Louisville* - 494 sonic soundings obtained en route Sydney, Australia, to Pearl Harbor, Territory of Hawaii, crossing 33° 31' 00" south in 176° 30' 30" west, 28° 59' 00" south in 167° 27' 00" west, 17° 36' 00" south in 149° 44' 30" west, 1° 43' 00" north in 155° 10' 00" west, and 16° 15' 00" north in 157° 54' 00" west.

U.S.S. *Mugford* - 893 sonic soundings obtained in the Atlantic and Caribbean Sea, crossing 24° 18' 30" north in 74° 24' 30" west, 19° 52' 48" north in 75° 12' 00" west, 20° 08' 00" north in 70°45'00" west, 23°24'24" north in 81°11'00" west, and 19°10'24" north in 69°13'36" west.

U.S.S. *Ramapo* - 1249 sonic soundings obtained en route Long Beach, California, to Manila, Philippine Islands, via Guam, Mariana Islands, crossing 33° 28' 48" north in 121° 03' 30" west, 30° 15' 30" north in 149° 18' 00" west, 24° 16' 06" north in 170° 58' 00" west, 20° 56' 00" north in 170° 31' 00" east, 17° 25' 00" north in 155° 47' 00" east, and 12° 45' 00" north in 124° 43' 42" east.

U.S.S. *Ralph Talbot* - 1143 sonic soundings obtained in unsurveyed area in the Atlantic and Caribbean Sea, crossing 24° 19' 00" north in 74° 17' 05" west, 19° 42' 00" north in 76° 57' 00" west, 21° 27' 20" north in 80° 10' 25" west, 21° 34' 30" north in 84° 29' 00" west, 26° 55' 30" north in 88° 47' 15" west, and 24° 02' 00" north in 81° 10' 00" west.

U.S.S. *Helm* - 812 sonic soundings in the Atlantic and Caribbean Sea, crossing 32° 35' 12" north in 73° 32' 00" west, 18° 57' 00" north in 67° 00' 00" west, 20° 03' 00" north in 73° 40' 00" west, 21° 53' 48" north in 77° 08' 00" west, and 25° 01' 30" north in 80° 08' 00" west.

U.S.S. *Trenton* - 526 sonic soundings obtained en route Hawaiian Islands to Australia and Singapore, crossing 20° 28' 30" north in 158° 04' 00" west, 07° 16' 00" north in 163° 16' 12" west, 38° 44' 18" south in 140° 03' 42" east, 35° 37' 42" south in 118° 00' 00" east, 18° 00' 00" south in 108° 41' 00" east, and 07° 39' 00" south in 105° 29' 00" east.

U.S.S. *Milwaukee* - 1272 sonic soundings obtained en route Hawaiian Islands to Australia and Singapore, crossing 20° 15' 30" north in 158° 02' 00" west, 11° 57' 55" north in 161° 26' 50" west, 06° 04' 50" south in 168° 15' 30" west, 32° 53' 42" south in 153° 24' 30" east, 38° 45' 18" south in 140° 32' 20" east, 21° 20' 30" south in 109° 37' 40" east, 15° 40' 15" south in 108° 00' 00" east, and 07° 36' 00" south in 105° 28' 30" east.

U.S.S. *Bushnell* - 466 sonic soundings obtained in the Atlantic and Caribbean Sea, crossing 24° 20' 00" north in 74° 13' 30" west, 19° 50' 00" north in 75° 14' 00" west, 15° 00' 00" north in 77° 03' 00" west, and crossing 09° 36' 00" north in 80° 03' 00" west.

U.S.S. *Arizona* - 253 sonic soundings obtained in Hawaiian Islands Area, crossing 29° 19' 00" north in 147° 45' 00" west, 32° 07' 12" north in 161° 42' 30" west, 21° 16' 00" north in 155° 56' 30" west, and crossing 20° 38' north in 157° 55' 30" west.

U.S.S. *Ramapo* - 1108 sonic soundings obtained en route Manila, Philippine Islands, to San Diego, California, crossing 12° 49' 00" north in 125° 19' 00" east, 13° 21' 30" north in 140° 51' 30" east, 27° 24' 00" north in 172° 03' 00" east, 31° 58' 00" north in 173° 36' 00" west, 35° 03' 00" north in 155° 14' 00" west, and crossing 33° 14' 00" north in 120° 45' 00" west.

U.S.S. *Somers* - 414 sonic soundings obtained during a shakedown cruise in West Indies, North and West coasts of Cuba and the Bahamas, crossing 21° 46' 36" north in 84° 59' 54" west, 21° 24' 12" north in 81° 07' 59" west, 20° 01' 30" north in 74° 33' 00" west, and crossing 24° 46' 24" north in 79° 50' 56" west.

U.S.S. *Erie* - 300 sonic soundings obtained in the Gulf of Panama, crossing 8° 20' 00" north in 79° 37' west, 06° 14' 00" north in 79° 30' west, and 03° 51' 00" north in 79° 44' 00" west.

U.S.S. *Philadelphia* - 1041 sonic soundings obtained in the Atlantic and Caribbean Sea, crossing 30° 00' 00" north in 77° 03' 00" west, 24° 00' 00" north in 72° 47' 00" west, 18° 33' 00" north in 66° 13' 00" west, 19° 10' 00" north in 67° 00' 00" west, 18° 59' 00" north in 65° 00' 00" west, and crossing 18° 35' 45" north in 63° 26' 00" west.

U.S.S. *Raleigh* - 73 sonic soundings obtained in vicinity of the Azores Islands crossing 39° 11' 54" north in 31° 14' 00" west.

U.S.S. *Warrington* - 2548 sonic soundings obtained in the Atlantic and Caribbean Sea, crossing 34° 51' 30" north in 75° 02' 30" west, 22° 02' 48" north in 74° 43' 24" west, 18° 25' 00" north in 74° 57' 30" west, 11° 30' 06" north in 74° 22' 06" west, 13° 16' 00" north in 62° 09' 06" west, 15° 39' 00" north in 63° 38' 48" west, and crossing 34° 56' 00" north in 75° 01' west.

U.S.S. *Ramapo* - 1184 sonic soundings obtained en route San Pedro, California, to Manila, Philippine Islands, via Dutch Harbor, Alaska, crossing 34° 17' 00" north in 121° 34' 00" west, 42° 40' 30" north in 140° 09' 00" west, 53° 28' 00" north in 162° 41' 30" west, 49° 25' 00" north in 176° 07' 06" west, 40° 21' 00" north in 172° 11' 30" east, 35° 09' 00" north in 163° 01' 00" east, 30° 28' 36" north in 149° 12' 06" east, and 20° 16' 00" north in 122° 11' 00" east.

U.S.S. *Hannibal* - 752 sonic soundings obtained en route La Guaira, Venezuela, to Cape Hatteras, via Mona Passage, crossing 10° 40' 30" north in 66° 57' 24" west, 15° 29' 48" north in 67° 11' 42" west, 19° 06' 18" north in 67° 41' 00" west, 22° 41' 48" north in 69° 56' 48" west and crossing 35° 12' 00" north in 75° 08' 48" west.

U.S.S. *Hannibal* (YP-42) - 313 sonic soundings obtained en route La Guaira, Venezuela, to Mona Passage, Puerto Rico, crossing 10° 39' 45" north in 66° 56' 00" west, 15° 18' 00" north in 66° 58' 00" west, and crossing 20° 53' 30" north and 69° 11' 05" west.

U.S.S. *Hannibal* (YP-41) - 346 sonic soundings obtained en route La Guaira, Venezuela, to Mona Passage, Puerto Rico, crossing 10° 36' 30" north in 66° 56' 00" west, 15° 53' 30" north in 67° 48' 20" west, and 21° 15' 00" north in 69° 30' 40" west.

U.S.S. *Rathburne* - 600 sonic soundings obtained around Hawaiian Islands, 21° 20' 00" north in 158° 20' 00" west.

U.S.S. *Savannah* - 677 sonic soundings obtained in the Atlantic and Caribbean Sea, crossing 28° 45' 00" north in 78° 24' 00" west, 22° 57' 00" north in 74° 38' 00" west, 18° 49' 00" north in 74° 33' 00" west, and crossing 21° 32' 00" north in 84° 22' 00" west.

U.S.S. *Nitro* - 407 sonic soundings obtained off California coast, 21° 43' 45" north in 110° 18' 00" west.

U.S.S. *Hannibal* - 524 sonic soundings obtained en route Port of Spain, Trinidad, British West Indies, to La Guaira, Venezuela, crossing 10° 38' 12" north in 62° 36' 54" west, 11° 12' 12" north in 63° 51' 12" west, 10° 10' 48" north in 65° 10' 06" west, and 10° 37' 30" north in 66° 56' 48" west.

U.S.S. *Hannibal* (YP-41 and YP-42) - 1422 sonic soundings obtained while on reconnaissance trip from Port of Spain, Trinidad, British West Indies, to La Guaira, Venezuela, crossing 10° 46' 15" north in 61° 48' 46" west, 11° 07' 30" north in 64° 36' 00" west, and 10° 38' 00" north in 66° 56' 00" west.

U.S.S. *Pickerel* - Ten sonic soundings obtained in the North Pacific, 35° 50' 00" north in 138° 35' 00" west.

U.S.S. *Vega* - 716 sonic soundings obtained in the Atlantic, Caribbean Sea, and Pacific Ocean, crossing 19° 25' 30" north in 75° 16' 00" west, 13° 08' 00" north in 79° 26' 12" west, 09° 24' 00" north in 87° 19' 06" west, 10° 33' 00" north in 90° 08' 00" west, 15° 24' 42" north in 101° 18' 36" west, and 19° 06' 00" north in 106° 36' 00" west.

U.S.S. *Charleston* - 538 sonic soundings obtained in the Caribbean Sea, crossing 15° 57' 18" north in 83° 55' 36" west, 20° 11' 00" north in 86° 58' 06" west, and 26° 05' 00" north in 97° 06' 00" west.

U.S.S. *Erie* - 1981 sonic soundings obtained en route Panama Canal Zone to Valparaiso, Chile, and return, crossing 1° 03' 30" north in 78° 31' 30" west, 19° 00' 00" south in 73° west, and 33° 00' 00" south in 71° 31' 00" west.

U.S.S. *Sirius* - 577 sonic soundings obtained en route Puget Sound to Canal Zone in North Pacific, crossing 31° 34' 30" north in 118° 42' 00" west, 24° 20' 30" north in 113° 04' 00" west, and 16° 18' 30" north in 100° 00' 00" west.

U.S.S. *Arkansas* - 1019 sonic soundings in the Atlantic and Caribbean Sea, crossing 39° 34' 00" north in 72° 00' 00" west, 25° 28' 00" north in 74° 21' 30" west, and 35° 16' 00" north in 75° 03' 48" west.

U.S.S. *Salmon* - 1447 sonic soundings obtained en route New London (Connecticut), to Guantanamo Bay, to Willemstad (Curacao), thence to Brownsville (Texas), Mobile (Alabama), and Habana (Cuba), crossing 30° 37' 30" north in 73° 00' 00" west, 14° 46' 00" north in 72° 52' 00" west, and 18° 10' 00" north in 78° 22' west.

U.S.S. *Ramapo* - 929 sonic soundings obtained en route Manila, Philippine Islands, to San Diego, California, crossing 18° 49' 12" north in 122° 17' 42" east, 28° 12' 00" north in 142° 33' east, 34° 27' 00" north in 169° 33' 00" east, 37° 14' 30" north in 170° 59' 00" west, 38° 12' 30" north in 155° 22' 00" west, and 33° 36' 30" north in 123° 45' 30" west.

U.S.S. *Charleston* - 578 sonic soundings in the Caribbean Sea, crossing 14° 37' 00" north in 79° 14' 00" west, 13° 34' 00" north in 80° 07' 00" west, 23° 10' 00" north in 82° 21' 30" west, and 25° 56' 00" north in 79° 20' 30" west.

U.S.S. *Langley* - 32 sonic soundings obtained en route San Francisco, California, to Sitka, Alaska, crossing 49° 28' 57" north in 127° 10' 15" west and 54° 25' 00" north in 133° 49' 30" west.

U.S.S. *Tuscaloosa* - 134 sonic soundings obtained in vicinity of the Hawaiian Islands, crossing 21° 30' 00" north in 157° 26' west and 48° 09' 00" north in 125° 18' 00" west.

U.S.S. *Seal* - 657 sonic soundings in the Atlantic and Caribbean Sea, crossing 22° 57' 48" north in 74° 17' 25" west, 19° 41' 15" north in 80° 36' 30" west, and 24° 20' 00" north in 83° 08' 00" west.

U.S.S. New York - 1008 sonic soundings obtained en route Norfolk, Virginia, to Portsmouth, England; Copenhagen, Denmark, and return, crossing 40° 41' 00" north in 43° 30' 06" west, 46° 01' 36" north in 28° 52' 30" west, and 47° 37' 00" north in 22° 54' 00" west.

U.S.S. Charleston - 296 sonic soundings obtained in the shoal area in North Pacific around 04° 31' 00" north in 84° 52' 00" west.

U.S.S. Erie - 1150 sonic soundings obtained while surveying over the Guardian Bank crossing 09° 24' 12" north in 87° 10' 50" west.

U.S.S. Skipjack - 657 sonic soundings in the Atlantic crossing 42° 41' 30" north in 64° 15' 15" west and 20° 28' 50" north in 73° 59' 00" west.

U.S.S. Texas - 538 sonic soundings in the North Atlantic, crossing 40° 54' 00" north in 43° 44' 00" west, and 40° 52' 00" north in 29° 41' 00" west.

U.S.S. Raleigh, Craven, and Bagley - 148 sonic soundings obtained while surveying over Guardian Bank (09° 00' 00" north in 88° 00' 00" west).

U.S.S. Snapper - 1774 sonic soundings obtained en route Norfolk, Virginia, to Valparaiso, Chile, via Crooked Island Passage and Panama Canal, crossing 23° 30' 00" north in 74° 18' 00" west, 18° 00' 00" north in 76° 00' 00" west, 16° 00' 00" north in 77° 18' 00" west, 10° 00' 00" north in 79° 18' 00" west, 04° 00' 00" north in 81° 30' 00" west, 04° 00' 00" south in 82° 50' 00" west, 14° 00' 00" south in 79° 18' 00" west, 18° 00' 00" south in 78° 10' 00" west, 27° 00' 00" south in 74° 25' 00" west, and 32° 43' 30" south in 71° 45' 00" west.

U.S.S. Gridley - 1409 sonic soundings obtained en route Norfolk, Virginia, to San Diego, California, via Guantanamo Bay and Panama Canal, crossing 22° 57' 30" north in 74° 47' 15" west, 20° 27' 30" north in 74° 05' 45" west, 13° 55' 00" north in 78° 30' 00" west, 07° 00' 00" north in 81° 52' 00" west, 15° 10' 15" north in 99° 00' 00" west, and 32° 48' 00" north in 117° 15' 00" west.

U.S.S. Enterprise - 160 sonic soundings obtained en route Norfolk, Virginia, to Rio de Janeiro, Brazil, crossing 29° 15' 00" north in 72° 22' 30" west, 12° 54' 36" north in 59° 27' 09" west, 05° 37' 00" south in 34° 29' 00" west, and 23° 12' 00" south in 41° 49' 15" west.

U.S.S. Enterprise - 511 sonic soundings obtained en route Rio de Janeiro, Brazil, to Guantanamo Bay, Cuba, crossing 22° 30' 45" south in 41° 07' 00" west, 17° 31' 30" south in 38° 08' 30" west, 04° 11' 30" south in 35° 57' 00" west, 03° 21' 00" north in 48° 31' 45" west, and 18° 27' 45" north in 74° 41' 45" west.

U.S.S. Honolulu - 330 sonic soundings obtained en route Norfolk, Virginia, to Portsmouth, England, and return to New York, crossing 37° 36' 00" north in 74° 00' 00" west, 40° 08' 00" north in 64° 05' 00" west, 45° 28' 00" north in 40° 00' 00" west, 49° 50' 00" north in 06° 10' 00" west, and return crossing 48° 10' 00" north in 15° 00' 00" west, 42° 08' 00" north in 41° 05' 00" west, and 40° 02' 00" north in 70° 35' 00" west.

U.S.S. Ramapo - 1429 sonic soundings obtained en route San Pedro, California, to Manila, Philippine Islands, via Guam, Mariana Islands, crossing 33° 21' 05" north in 121° 00' 00" west, 30° 23' 08" north in 148° 48' 00" west, 27° 46' 00" north in 174° 54' 08" west, 21° 59' 30" north in 164° 05' 00" east, and 12° 48' 30" north in 125° 28' 00" east.

U.S.S. Vega - 431 sonic soundings obtained in the North Pacific along the coast of Lower California, crossing 32° 12' 48" north in 117° 15' 06" west, 24° 27' 00" north in 114° 26' 30" west, and 19° 06' 00" north in 107° 31' 18" west.

U.S.S. Ramapo - 905 sonic soundings obtained en route Cavite, Philippine Islands, to Mare Island, California, crossing 16° 12' 00" north in 119° 37' 00" east, 33° 18' 00" north in 156° 06' 00" east, 37° 35' 30" north in 179° 21' 00" west, and 37° 39' 00" north in 124° 00' 00" west.

U.S.S. Vega - 196 sonic soundings obtained in the Caribbean Sea, from Panama Canal to Navassa Island and eastern coast of Cuba, to San Salvador Island, crossing 15° 17' 12" north in 78° 33' 30" west, 18° 15' 00" north in 75° 04' 06" west, and 21° 31' 00" north in 74° 44' 36" west.

U.S.S. Skipjack - 718 sonic soundings obtained in the Caribbean Sea from Guantanamo Bay to Coco Solo, Panama Canal, thence to Cienfuegos, Cuba, and New Orleans, Louisiana, crossing 19° 34' 00" north in 75° 26' 00" west, 10° 31' 00" north in 79° 04' 00" west, 16° 43' 00" north in 81° 00' 00" west, and 21° 20' 00" north in 81° 32' 30" west.

U.S.S. Philadelphia - 48 sonic soundings in the Caribbean Sea, from Mouchoir Passage to Samana Bay and Puerto de Trujillo, crossing 21° 02' 48" north in 71° 09' 00" west.

U.S.S. Nashville - 423 sonic soundings obtained in the North Atlantic en route Guantanamo Bay, Cuba, to Cherbourg, France, and Portsmouth, England, and return to New York, crossing 27° 00' 00" north in 66° 57' 00" west, 34° 23' 00" north in 57° 17' 00" west, 49° 12' 30" north in 12° 47' 00" west, and return trip to New York, crossing 49° 10' 00" north in 09° 44' 00" west, 46° 20' 00" north in 27° 26' 00" west, and 42° 00' 00" north in 58° 29' 30" west.

U.S.S. Bushnell - 300 sonic soundings obtained around Crooked Island Area, crossing 21° 52' 00" north in 74° 24' 00" west and 24° 20' north in 74° 33' 00" west.

U.S.S. Philadelphia - 208 sonic soundings obtained in the Caribbean Sea from Port au Prince Bay, Haiti, to Guantanamo Bay, Cuba, crossing 18° 35' 12" north in 72° 50' 30" west and 19° 52' 12" north in 75° 10' 12" west.

U.S.S. Dunlap - 715 sonic soundings obtained en route Norfolk, Virginia, to San Pedro, California, via Panama Canal, crossing 22° 50' 30" north in 74° 27' 48" west, 18° 26' 00" north in 75° 59' 18" west, 08° 44' 06" north in 87° 23' 12" west, 12° 26' 30" north in 94° 42' 00" west, and 19° 58' 00" north in 110° 57' 00" west.

U.S.S. Ralph Talbot - 80 sonic soundings in the North Atlantic off Block Island, crossing 39° 30' 00" north in 72° 10' 00" west.

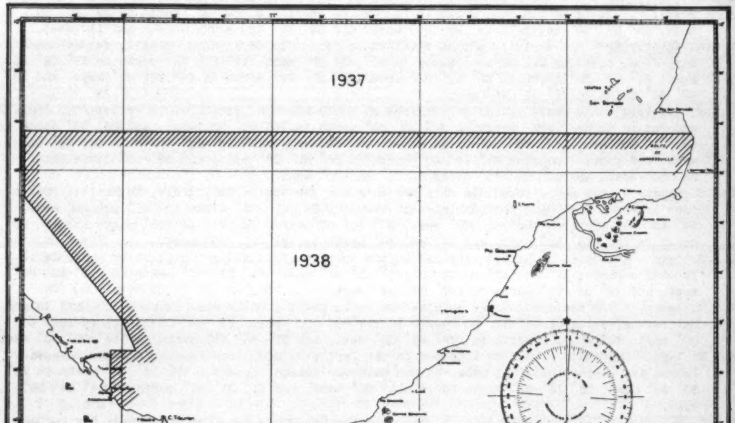
U.S.S. Houston - 274 sonic soundings obtained en route San Pedro, California, to Galapagos Islands, crossing 24° 00' 00" north in 111° 28' west, 21° 00' 00" north in 110° 09' 00" west, 15° 00' 00" north in 110° 13' 00" west, 06° 00' 00" north in 99° 43' 00" west, 0° 05' 00" north in 90° 14' 00" west, and 01° 18' 00" south in 89° 42' 00" west.

U.S.S. Holland - 464 sonic soundings obtained in the North Pacific, between Aleutian Islands and San Pedro, California, crossing 32° 51' 30" north in 118° 02  30" west and 53° 55' 00" north in 163° 27' 00" west.

U.S.S. Arizona - 15 sonic soundings obtained off coast of California, crossing 35° 24' 40" north in 123° 12' 00" west.

U.S.S. Erie - 1275 sonic soundings obtained off west coast of Central America, crossing 07° 05' 48" north in 80° 12' 12" west, 06° 09' 54" north in 81° 51' 54" west, 12° 50' 00" north in 88° 06' 00" west, and 13° 29' 54" north in 90° 08' 13" west.

Since the publication of the bathymetric chart of the South Pacific Ocean, reported upon at the annual meeting in 1938, a similar chart of the Caribbean Sea, compiled jointly by this Office and Dr. Harry H. Hess, of Princeton University, has been completed and published. It will form part of the final report of the Navy-Geophysical Union Gravity Expedition of 1936-1937.



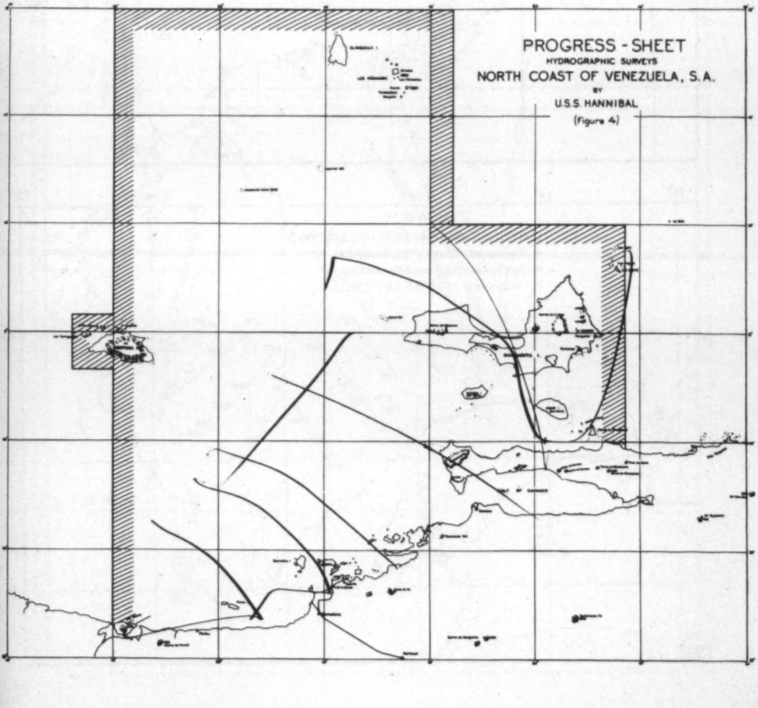
PROGRESS-SHEET
HYDROGRAPHIC SURVEYS
NORTH COAST OF COLOMBIA, S.A.
BY
U.S.S. BUSHNELL
(Figure 3)

During the year the Hydrographic Office continued its surveying operations in Central American Waters (Fig. 3). The U.S.S. Bushnell completed the survey of the north coast of Colombia from Punta San Bernardo westward to Punta Carreto in Panama, including the Gulf of Darien, covering during the season a total of over 6000 square nautical miles and a coast-line extending 300 nautical miles.

The U.S.S. Hannibal finished the survey of Boca Grande, Venezuela, and Approaches (Fig. 4), an area comprising over 1100 square nautical miles, and is now engaged in a survey of the north coast of Venezuela from the mouth of the Unare River to Ercarcero Point, including the off-lying islands. The present charts of this region are based on Spanish surveys made over a century ago.

During 1938 the U.S.S. Bushnell added to the network of dynamic sounding stations on the east coast of Central America (Fig. 5) by occupying 32 stations contiguous to the coasts of Panama and Colombia. The work in this area was commenced by the U.S.S. Hannibal in 1936, and a total of 98 stations have now been occupied. The data obtained have been forwarded to the Bingham Oceanographical Laboratories for investigation.

In cooperation with the Scripps Institution of Oceanography, the U.S.S. Bushnell will occupy in 1939 a line of dynamic stations between Balboa and San Diego, and another line from San Diego to the Hawaiian Islands (Fig. 6). The latter line should offer an interesting comparison with the previous line run by the U.S.S. Louisville in 1936 and earlier soundings by the Carnegie. A representative of the Scripps Institution of Oceanography will accompany the Bushnell from Balboa to San Diego.


PROGRESS - SHEET
HYDROGRAPHIC SURVEYS
NORTH COAST OF VENEZUELA, S.A.
BY
U.S.S. HANNIBAL
(Figure 4)

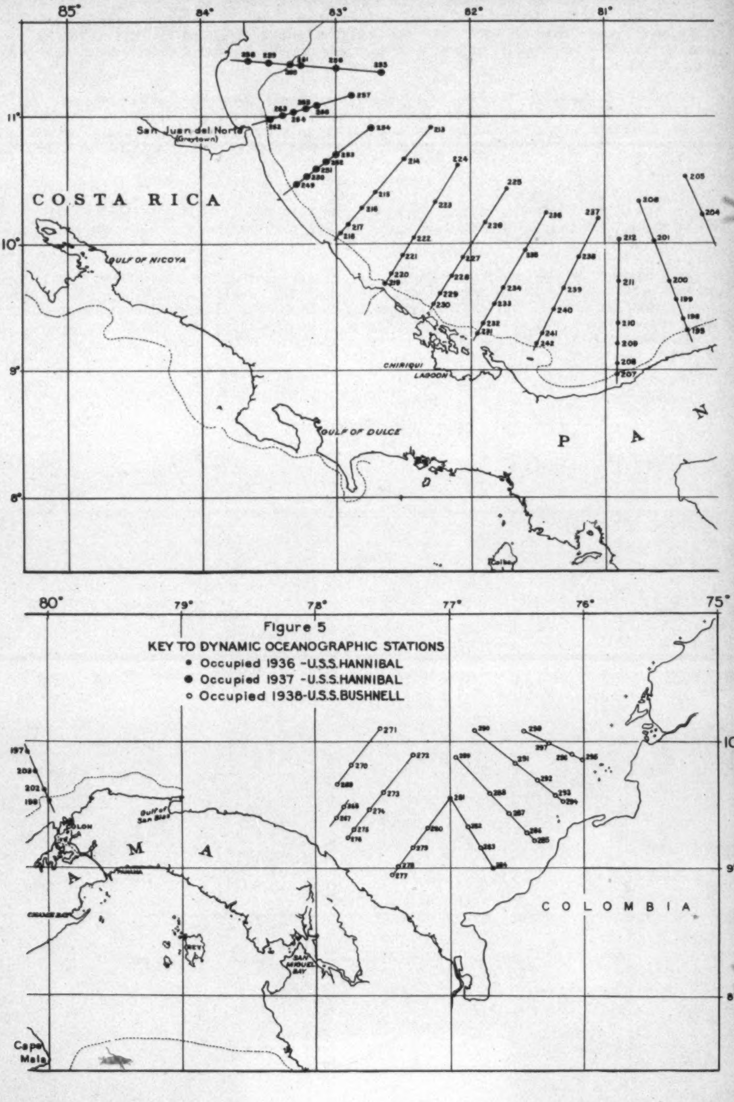

85°
84°
83°
82°
81°
11°
10°
9°
8°
San Juan del Norte
(Greytown)
COSTA RICA
GULF OF NICOYA
GULF OF DULCE
CHIRIQUI
LAGOON
P A N
A M A
Coiba
80°
79°
78°
77°
76°
75°
Gulf of San Blas
COLON
PANAMA
CHAME BAY
REY
SAN MIQUEL BAY
Cape Mala
COLOMBIA

Figure 5

KEY TO DYNAMIC OCEANOGRAPHIC STATIONS

- • Occupied 1936 - U.S.S. HANNIBAL
- ● Occupied 1937 - U.S.S. HANNIBAL
- ○ Occupied 1938 - U.S.S. BUSHNELL

The various lines on the chart show the extent of the dynamic survey work of the United States Naval vessels in the Pacific since its inauguration in 1933. A projected line from Panama to the Hawaiian Islands is also included which will be occupied in the future when opportunity permits.

The year 1938 marked an expansion in the program of ocean-current and sea-surface temperature-correlation, being conducted by the Hydrographic Office through the aid of Government-sponsored projects. Originally commenced during 1936, in California, under the joint sponsorship

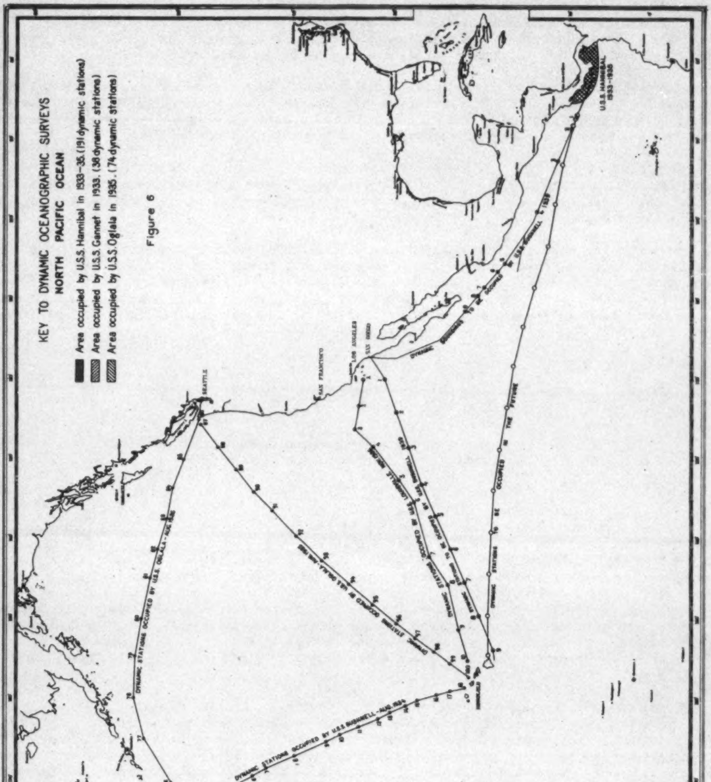

KEY TO DYNAMIC OCEANOGRAPHIC SURVEYS
NORTH PACIFIC OCEAN
■ Area occupied by U.S.S. Hannibal in 1933-35. (191 dynamic stations)
▨ Area occupied by U.S.S. Gannet in 1933. (38 dynamic stations)
▨ Area occupied by U.S.S. Oglala in 1935. (74 dynamic stations)
SEATTLE
SAN FRANCISCO
LOS ANGELES
SAN DIEGO
HONOLULU
U.S.S. HANNIBAL 1933-1935
U.S.S. GANNET 1933
U.S.S. OGLALA 1935
DYNAMIC STATIONS OCCUPIED BY U.S.S. OGLALA-AUG. 1935
DYNAMIC STATIONS OCCUPIED BY U.S.S. BUSHNELL-AUG. 1934
DYNAMIC STATIONS TO BE OCCUPIED IN THE FUTURE

Figure 6

of this Office and the Scripps Institution of Oceanography, to evaluate the data pertaining to the Pacific Ocean for the period 1925-34, it became possible in 1938 to extend operations to additional projects in New Orleans and Philadelphia, and thus embrace all material relating to every ocean for the period 1904-34. At the present time all data for the Pacific Ocean, comprising over one million observations, have been tabulated for surface-temperatures and currents, and the work of analyzing these data is progressing rapidly. Similar treatment for over three million observations covering the other oceans has been commenced. It is hoped that by the end of next year monthly surface-temperature charts of the North and South Pacific Ocean will be completed, showing the maximum, minimum, and average temperatures for each one-degree quadrangle, together with isothermal lines and other cognate data. The issuance of these charts will be followed by monthly current-charts depicting the resultant current-drifts in the one-degree quadrangles. Eventually similar charts of all oceans will be compiled and published.

The completion of these projects will make available to the oceanographer and meteorologist a compendium of oceanic data, of proportions much too vast to have been compiled by private enterprise, which will aid materially in the solving of many existing problems relative to oceanic circulation, atmospheric and climatic conditions, and kindred questions.

In closing, I know that the members of the Union will be interested in learning that Captain Lamar R. Leahy, my predecessor, has just been elected to serve as a Director of the International Hydrographic Bureau, Monaco, an institution that is doing much to advance the interests of oceanography throughout the world.

The scope of the oceanographic activities of the Hydrographic Office and the United States Navy depends in a large measure upon the cooperation of interested scientific bodies, and in this connection I wish to express my appreciation to the various oceanographic institutions for their valuable assistance in furthering the work of this Office, and to assure you that the facilities of the Hydrographic Office are always at the disposal of those who in the course of their investigations desire to utilize the material collected by it.

Hydrographic Office,
U. S. Navy,
Washington, D. C.

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## CONTRIBUTIONS TO OCEANOGRAPHY, UNITED STATES COAST AND GEODETIC SURVEY

L. O. Colbert

Coastal surveys contribute to the advancement of the science of oceanography in two major respects. The topography of submarine regions surveyed, yield, of course, a quantity of facts bearing upon the geomorphology of the areas, but more important, is the fact that well-controlled surveys make possible standard base-charts of the major features of the ocean-floor, and such charts will enable future investigators to locate themselves definitely by means of echo-sounding. More quantitative results should thus be obtained from better knowledge of positions of dredged specimens, core-samples, geophysical, and oceanographic observations made along the Continental margins within the areas so surveyed and charted. Repeat-observations at the same station or the collection of specimens from sections immediately adjacent to some previous well-defined section will be possible.

During the past few years additional facts in the nature of more soundings, accurately located, have been largely responsible for the new light that has been shed on oceanographic questions relating to Continental margins. Perhaps we are just beginning to realize the complexity of the parts of the Earth's history available in the physiography of the sea-bottom near our shores. Paradoxically, however, the addition to knowledge of the configuration of the sea-bottom has also raised many new questions--even controversies--that involve quite a category of Earth-sciences.

The vast quantity of soundings now available, coupled with the ever-growing needs for more complete charts, not only for nautical use, but also for science, places a whole series of new problems before us. Among these are: The task of making available all soundings by proper publication; the interpretation of the forms shown by the soundings; and, making plans for future investigation. It is not my intention to discuss these problems at length, nor do I consider it desirable to explain again the new methods and equipment responsible for our basic facts. These have been described from time to time in past "Transactions" of the American Geophysical Union.

Oceanographers are particularly indebted to the late Dr. A. C. Veatch for initiating and directing a project for the publication of the results of a section of the surveys, in a manner that will make all the data available to interested students. This project was undertaken cooperatively with the Geological Society of America. The charts of the Continental Shelf and Slope that are the result of this work are exhibited here. The charts are published in three forms. One copy contains soundings and contours, one has contours and stream-lines without soundings, and one copy has soundings only. The prints of each chart containing soundings and contours, and stream-lines are to be issued by the Geological Society of America with Special Paper Number 7, and the copies containing soundings only will be available through the United States Coast and Geodetic Survey. Dr. Veatch was assisted in this project by Lieutenant Paul A. Smith, United States Coast and Geodetic Survey, who is now responsible for the completion of the work. This complete project represents an example of one manner in which such data may be handled. I believe that it is most essential at this time to publish all the soundings as was done in this project with any interpretations of data of this nature.

A compilation of the surveys of the Atlantic Continental Shelf with one-fathom contours in the region between the shore and the edge of the Shelf is now being carried out in the Bureau. It is yielding many physiographic shapes that are considered highly significant in the recent geologic history of the Atlantic Coastal Plain. More complete knowledge of the shelf-forms, afforded by the shelf-compilations, undoubtedly will have an important bearing upon the regional aspects of beach-erosion, as pointed out by Colonel E. I. Brown, Corps of Engineers, in his recent paper on beach-erosion studies [Earl I. Brown, Beach erosion studies, Proc. Amer. Soc. Civ. Eng., v. 65, No. 1, pp. 69-91 (1939)].

Speaking in the broadest sense, the world-wide problems of mapping ocean-floor topography may be resolved into two major classifications: (1) The task of compiling, correlating, and publishing the deep-sea lines of echo-soundings, which provide a wealth of information of a reconnaissance or exploratory nature, and (2) the more thorough investigation of details in regions where the reconnaissance indicates that there may be certain significant facts to be learned from additional work.

I hardly need point out that the systematic accomplishment of the first part of such a program will require the combined efforts of skilled hydrographers and physiographers. But certainly some constructive thought needs to be given towards a plan which will at least direct the energies of future expeditions into the regions where we can, in the light of new knowledge, expect the most returns for the work and money invested. This Section of the American Geophysical Union and other interested organizations should give some active thought toward these problems. Not the least is the matter of publication of results.

Little more can be added at this time except to point out the progress of coastal surveys during 1938. On the Atlantic Coast of the United States, offshore surveys for nautical charts have now been extended to cover an area between the Chesapeake Bay Entrance and the eastern extremity of Georges Bank, excepting for one season s work between Block Island and Nantucket Island. This section will probably be filled in during 1939 by the parties of the ships Oceanographer, Lydonia, and Gilbert. Pacific Coast basic offshore surveys were extended to fill in most of the gap in the vicinity of Cape Mendocino, by the ship Guide. In the Gulf of Mexico the ship Hydrographer extended surveys westward along the Texas Coast so that the season of 1939 should see the completion of the offshore work as far as the Mexican Border.

In Alaska, the work was carried further westward along both sides of the Aleutian Islands by the ships Surveyor and Pioneer, and by the Discoverer along the south side of Unimak Island. During the 1939 season the three ships mentioned and the Guide will work in the Aleutian Islands, along Unimak Island, and on the Bering Sea side of the Alaska Peninsula.

The Pathfinder continued surveys in the Philippine Islands on the west coast of Palawan Island. No additional work was done in the Hawaiian Islands in 1938 and none is contemplated for 1939. Six additional deep-sea lines were run across the Gulf of Alaska by the Surveyor, Discoverer, and Pioneer en route to and from the Aleutian Islands, and similar additional work will be done in 1939.

A few words might be said about new equipment in the Survey. Two new surveying vessels are now being built to replace present ships long past their period of economic operation. One is a steel vessel of 1500 tons under construction in Seattle, Washington; another, a wooden tender of 130 tons, is under construction in Astoria, Oregon. A new water-specimen cup developed in the Instrument-Division is being tried out and promises to be an improvement over the older types.

A contract has been let for a number of new graphic recording Fathometers for use on launches.

The new echo-sounders using a supersonic frequency are to be operable from launches, whaleboats, or small craft requiring only a 12-volt storage-battery.

Six large Fathometers of the Dorsey No. III design are to be delivered to the Bureau this year. These instruments are designed to obtain depths between a few feet and several thousand fathoms beneath the hull.

For position finding by echo-sounding, a different type of chart is desirable, and to serve this purpose the first of its kind has just been issued. This chart covers the region between San Diego and Santa Rosa Island, Coast of California, and contains 50-fathom contours in blue. With such a chart, designed especially for echo-sounding navigation, it will be possible for scientific expeditions to add greatly and in a quantitative manner to the Earth-sciences of which oceanography is only one, by further investigation of the many details indicated by the major features so charted.

In the field of tides, the United States Coast and Geodetic Survey during 1938 continued and expanded its program of maintaining tide-stations throughout the coastal area of the Country. Apart from the practical needs supplied by long-series observations, the results afford the only definite criterion for recent changes in elevation between land and sea.

Twelve stations are in operation for special surveys over a one-year period in the Sacramento-San Joaquin Waterway, and seven on the Connecticut River in cooperation with the United States Engineers. Additional surveys of this type are urgently needed, especially on the Atlantic and Gulf coasts.

Many agencies cooperate in assisting to maintain tide-stations. Among these at present are the United States Engineers, United States Navy, the Lighthouse Service, Scripps Institution of Oceanography, Woods Hole Oceanographic Institution, Oceanographic Laboratories of the University of Washington, Chesapeake Biological Laboratories, State of Texas, Territory of Hawaii, City of Los Angeles, City of Santa Monica, and the Port of Willapa Harbor.

In the related field of currents, hourly observations were continued in cooperation with the Lighthouse Service covering a number of months at three lightships located in the approaches to New York Harbor, namely, Ambrose Channel, Scotland, and Fire Island Lightships. Comprehensive current-surveys that are needed in a number of important harbors and waterways have been postponed due to lack of funds. A study of the currents in San Pedro Channel, California, covering observations over five months at a point seven miles south of Los Angeles Harbor Breakwater was issued during the year.

In conclusion I should like to express my appreciation to the cooperating organizations for their active interest in numerous matters of importance to the nautical and scientific public. I wish to extend to the members of this Union the assurance that we shall welcome opportunities to make available to them the results of the data accumulated in the course of the various activities of the United States Coast and Geodetic Survey.

U. S. Coast and Geodetic Survey,
Washington, D. C.

## THE OCEANOGRAPHIC WORK OF THE UNITED STATES COAST GUARD IN THE WESTERN NORTH ATLANTIC IN 1938 AND PLANS FOR 1939

R. R. Waesche

In connection with the work of the International Service of Ice Observation and Ice Patrol the United States Coast Guard assigned as patrol-cutters the *Tahoe* and *Pontchartrain* for the season of 1938. The 125-foot patrol-boat *General Greene* was again assigned as the oceanographic vessel of the Ice-Patrol Force. The ice-observation officer, who has charge of the scientific work on the patrol-cutters, was Lieutenant G. Van A. Graves, and the oceanographer in charge of the scientific work on the oceanographic vessel was Floyd M. Soule.

During February 12 to July 22, 1938, the two patrol-cutters made 11 cruises of about two weeks each in the region of the Grand Banks of Newfoundland. An equal number of fortnightly sea-surface isothermal charts of the usually ice-infested area in the vicinity of the Grand Banks were prepared from several thousand temperature-reports received by the patrol-cutters from passing steamers and will be published in United States Coast Guard Bulletin No. 28. The Ice-Patrol was discontinued for the season on July 22, 1938.

The General Greene spent the months of April, May, June, and the first part of July supplying dynamic topographic charts of the Grand Banks Region to the patrol-cutters. During this period four current-surveys of the critical area were made, the resulting charts being referred to the 1000-decibar surface although at most of the oceanographic stations the temperature- and salinity-measurements extended to a depth of 1400 meters where the depth of water permitted. In this work 268 oceanographic stations were occupied. During the third survey, early in June, a section occupied near the 50th meridian was extended southward from the Tail of the Grand Banks across both the Labrador Current and Gulf Stream as far south as latitude 39°. On this section temperature- and salinity-measurements extended to a depth of between 2000 and 2500 meters. This section should be of added interest in the light of the cooperative international survey-work undertaken at about the same time in the vicinity of the Azores.

From July 22 to August 17, 1938, the General Greene occupied an additional 39 oceanographic stations during a post-season cruise in the Labrador Sea. Most of these stations were occupied from the surface to as near bottom as was practical, serial observations of temperature and salinity being made at all stations. These stations were disposed in the form of the following sections: (1) South Wolf Island, Labrador, to Cape Farewell, Greenland; (2) longitudinal section from section (1) to Davis Strait Ridge; (3) on Davis Strait Ridge from the "West Ice" to Holsteinsborg, Greenland. In addition to the temperature- and salinity-observations, samples were collected for the determination of dissolved helium and oxygen from section (2) and from three stations in the middle of section (1). Unfortunately the mercury seals on the helium samples leaked. However, the oxygen determinations proved to be of great interest in themselves and in providing new information regarding the circulation in, and production of, bottom-water of the Labrador Sea and of the Western North Atlantic. Also on the post-season cruise, 451 fathometer-soundings were taken along the previously mentioned sections. The soundings have been corrected, tabulated, and supplied to the United States Hydrographic Office and the International Hydrographic Bureau. A continuous sonic-sounding section was made along the Continental Shelf from Davis Strait to the Strait of Belle Isle to obtain information regarding the existence or nonexistence of submarine canyons in this region. Because of other considerations this section was run along the middle of the Shelf, which is not the ideal location for such a section. No canyons were found this far inshore.

Since the Union's nineteenth annual meeting in 1938, United States Coast Guard Bulletin No. 27 by Floyd M. Soule and G. Van A. Graves has appeared in print. This bulletin deals with the results of the season of 1937 and post-season cruises. United States Coast Guard Bulletin No. 28, also by Soule and Graves, is now in press and contains a discussion of the results of the work in 1938 which has been outlined here. The oceanographic section of this Bulletin may be summarized as follows:

(1) The four current-surveys of the Ice-Patrol Area in the vicinity of the Grand Banks, made during the 1938 season, have been described.

(2) Computations have been made and the results presented to show the seasonal variation of the Labrador Current during 1938 as compared with similar variations found during the previous four ice-seasons.

(3) The boundary between Atlantic-Current water and Labrador-Current water, based on the horizontal projection of the course of the zero-salinity anomaly at the intermediate salinity-anomaly maximum, was investigated but found to be outside the limits of the surveys of 1938.

(4) A section across the Gulf Stream near the 50th meridian, occupied during June, 1938, has been discussed with respect to volume of flow, heat-transport, and mean temperature.

(5) Quantitative consideration has been given an actual section with regard to the magnitude of the effect of a storm-produced, hypothetically uniform, vertical mixing of the upper 100 meters.

(6) The circulatory system of the upper layers of the Labrador Sea has been discussed from the standpoint of volumes of flow, mean temperatures, and heat-transport values derived from measurements made during 1938 on sections across the Labrador Current off South Wolf Island, across the West Greenland Current off Cape Farewell, across the west-flowing branch of the West Greenland Current south of Davis Strait Ridge, and across a part of the Baffin Land Current and the West Greenland Current at Davis Strait.

(7) New data on the oxygen distribution along a longitudinal section through the northern part of the Labrador Sea are presented and discussed with relation to the source of the bottom-water of the Labrador Sea.

The program for 1939 of scientific work is already under way. The Chelan and Champlain are the ships which have been assigned as patrol-cutters for 1939. The General Greene as oceanographic vessel of the Ice-Patrol Force is engaged in supplying dynamic topographic charts of the Grand Banks Region to the patrol-cutters as in previous years. At the present, the second current-survey of the season is in progress. This current-map service will be continued until the end of the ice-patrol season, after which the General Greene will begin a short post-season cruise. Tentative plans for this cruise call for an oceanographic section across the Labrador Sea from South Wolf Island, Labrador, to Cape Farewell, Greenland.

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# THE INFLUENCE OF VERTICAL AND LATERAL TURBULENCE ON THE CHARACTERISTICS OF THE WATERS AT MID-DEPTHS

C. O'D. Iselin

(Contribution No. 220 of the Woods Hole Oceanographic Institution)

In a previous paper (Iselin 1936) the writer considered that the temperature and salinity of the main thermocline layer (400-1200 meters) in the Sargasso Sea were mainly determined by vertical turbulence. At that time special significance was attached to the very consistent temperature-salinity correlation at mid-latitude stations from the western North Atlantic. Thus, when plotted on a temperature-salinity diagram, the great majority of the modern observations fell along a narrow and slightly curving path connecting the characteristics of the superficial layer with those of deep water. The fact that in the main thermocline the temperature-salinity correlation was somewhat fresher than a pure mixture of deep water and surface-water was thought to result from the inflow of relatively large volumes of subantarctic intermediate water which appeared to enter the Sargasso Sea in two ways. First, this low-salinity layer seemed to penetrate northward across the Northern Equatorial Current at mid-depths and second, a considerable volume of it was observed leaving the Florida Straits to be discharged into the Sargasso Sea along the southern edge of the Gulf Stream. In short, it was considered that the negative salinity-anomalies brought to the Sargasso Sea by the subantarctic intermediate layer more than counteracted the positive anomalies arriving at similar depths from the westward flow of water carrying Mediterranean characteristics.

While in this view the existence of lateral movements was recognized in the case of the subantarctic and Mediterranean layers, it was thought that only by the upward mixing of deep water could the apparently rapid renewal of the bottom-water be explained. Therefore, it seemed likely that through vertical turbulence everywhere in the Sargasso Sea deep-water characteristics were being transferred to mid-depths and blended with those of the superficial layers, a portion of this mixture being carried to the north in the northern branch of the North Atlantic Current. Only in this way did it seem possible to explain the high oxygen-content of the deep water, which seemed to demand a relatively rapid, large-scale vertical circulation.

Because of the very slight lateral gradients in the Sargasso Sea, it appeared doubtful in 1936 that lateral turbulence could possibly outweigh vertical turbulence in determining the characteristics of the waters at mid-depths. Therefore, the subantarctic and Mediterranean influences were thought of as mass-movements, rather than as the lateral transfer of these characteristics through turbulence. Since that time, a number of papers (Rossby 1936, Parr 1936 and 1938, Montgomery 1938) have been published emphasizing the rôle of lateral turbulence in the sea. Evidence has been brought forward (Rossby 1936, Sverdrup 1938) that the coefficient of lateral turbulence may be as much as a million times greater than that of vertical turbulence. The meteorological principle of isentropic analysis, which stresses lateral mixing on surfaces of constant density, assumes that lateral turbulence entirely surpasses vertical turbulence in determining the characteristics of the waters at mid-depths. The only serious objection to this point of view lies in the high oxygen-content of the bottom-water. Unless this water is mixed vertically and carried off to the north at a relatively rapid rate, it is difficult to understand how its rich oxygen-load can be maintained. Nevertheless, much evidence has accumulated in recent years that at mid-depths lateral turbulence is much more effective than was formerly supposed.

Montgomery's (1938) analysis of the observations of temperature, salinity, and oxygen from the region of the Northern Equatorial Current shows that at least down to the surface $\sigma_t = 27$ (400-700 meters) the principle of isentropic mixing is nicely confirmed. For the layers he studied, the characteristics of each surface of constant density could be traced upstream to where it

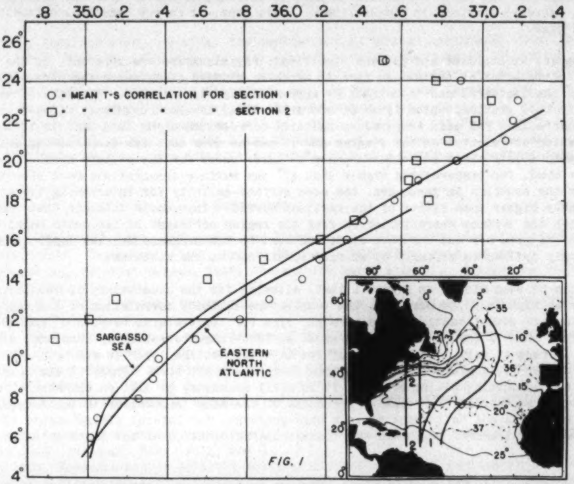

FIG. 1

cut the wind-stirred surface-layer. The question at once arises as to whether or not the same principle holds good for more northern waters and at greater depths. In other words, can the temperature-salinity correlation at mid-depths in the Sargasso Sea be explained by lateral turbulence, rather than by vertical turbulence accompanied by certain lateral mass-movements at mid-depths as described above?

The diagram presented here (Fig. 1) was constructed as a preliminary step in the study of this question. So many problems are involved that no single approach should be considered conclusive. Nevertheless, the outcome is on the whole favorable to the belief that lateral mixing has been sadly neglected until recently in most studies of the circulation-problem.

The temperature-salinity correlation of the sea-surface of course varies widely with the seasons. For the greater part of the North Atlantic and during most of the year a shallow secondary thermocline blocks off the surface-water from the deeper, main thermocline layer with which we are here concerned. However, at the underside of the shallow secondary thermocline the winter characteristics of the sea-surface persist almost unchanged throughout the year. It is not unreasonable then to suppose that the temperature-salinity correlation of the sea-surface in mid-winter has a special significance in determining the characteristics of the waters at mid-depths. This will be true whether vertical or lateral turbulence is the agency for the downward transfer of these characteristics.

Since the maximum cooling of the sea-surface is probably reached in March, a large chart was prepared on which both the March surface-isotherms and isohalines were plotted. These were copied from diagrams published by Böhnecke (1936). No doubt the temperature-chart is considerably more exact than the salinity-chart, for which much fewer observations were available. While the March surface-isotherms and isohalines in general parallel each other, the latter take a more wavy path so that there are many intersections. In addition, it is evident that in the western part of the ocean, especially north of the Gulf Stream System, the sea-surface in March is considerably fresher for a given temperature than it is in the east.

The temperature-salinity correlation along various north-south trending sections was next examined. Because of the wavy course of the isohalines, no single section seemed representative, but if the fresher waters north of the Gulf Stream are excluded, all temperature-salinity curves of the surface-layer in March more or less follow the mean vertical temperature-salinity curve (Iselin 1936) for the Sargasso Sea. In other words, the temperature-salinity correlation of the surface-layer of the North Atlantic in winter is not very different from the vertical temperature-salinity curve at stations in mid-latitudes. This fact, of course, has been generally appreciated for some time.

However, much closer and perhaps significant relationships are apparent, if the temperature-salinity correlation of the sea-surface in March is studied along a curving mid-ocean section that cuts the isotherms and isohalines at approximately right-angles. The path (inset chart in Fig. 1) of this section, which is about 300 miles wide, is also roughly at right-angles to the surface-currents. The mean temperature-salinity correlation along this band is indicated by the circles which are plotted on the diagram and it can be seen that for temperatures between 6° and 11° the points fall close to Helland-Hansen's (1926) curve for the eastern North Atlantic. On the other hand, for temperatures higher than 17° the surface-observations more closely follow the curve for the southern Sargasso Sea, the mean surface-salinity for intervening temperatures being considerably higher than either of the vertical curves. This would indicate that isopicnal mixing carries the surface-characteristics from the region northeast of the Grand Banks down to mid-depths in the area off the European Coast and that in the Sargasso Sea the upper layers are correspondingly influenced strongly by surface-conditions to the southeast.

It can be seen also from Figure 1 that, allowing for the uncertainty of the salinity-values (possibly as high as ±0.05 per mill, the temperature-salinity correlation of the surface-layer does not depart significantly from a straight line for temperatures between 6° and 23°. The Figure suggests that if the downward transfer of surface-characteristics by isopicnal mixing were the only process at work, the salinity of the main thermocline layer in mid-latitudes would be somewhat higher for a given temperature than is actually the case. Thus, if the lateral turbulence is the dominating mixing process, it is still necessary to call on the subantarctic intermediate layer to explain the relative freshness of the main thermocline in the Sargasso Sea. However, this need not be thought of as a mass-movement, for lateral mixing alone, if sufficiently vigorous, can transfer northward the fresher characteristics of the South Atlantic at mid-depths.

A further consideration of Figure 1 provides evidence that lateral turbulence only causes effective transfer of physical properties in a direction having a marked down-stream component. In other words, the relatively dense surface-waters of the southern Labrador Sea most closely resemble the temperature-salinity correlation at mid-depths off the European Coast, while the lighter surface-waters of the Northern Equatorial Current are found relatively unchanged at moderate depths in the southwestern Sargasso Sea.

The rather weak cross-current component of lateral mixing is further emphasized by a consideration of the temperature-salinity correlation at the surface along a north-south section, extending southward from the Nova Scotia Continental Shelf. The squares in Figure 1 show the mean temperature-salinity relationship in March along this band. North of the Gulf Stream in the so-called slope-water area the surface-waters have a density close to 26.5 in winter, but as it crosses the Gulf Stream this isopicnal descends to a depth of about 400 meters. It might be expected that lateral turbulence would carry the fresh, cold characteristics of the surface-layer north of the current downward and across it into the Sargasso Sea, just as it does in the case of the subarctic intermediate water further to the east. Only by assuming rather specialized conditions within the Gulf Stream west of the Grand Banks can this apparent paradox now be explained [Rossby (1936) has argued that because the Gulf Stream can be compared to a wake-stream and because the volume of the slope-water is rather small, the current will tend to absorb water along its southern side and to discharge water to the north. Thus, while the current is increasing rapidly in volume, the transfer southward of slope-water characteristics by lateral mixing may be blocked.]

The failure of lateral turbulence to transfer the very definite characteristics of the surface-layer of the slope-water band across the Gulf Stream is admittedly a puzzling point and one which seems unfavorable to a large coefficient of lateral mixing. A special study of this sector of the Gulf Stream is now nearly ready for publication, so the matter will not be enlarged upon here. However, except for the area between Cape Hatteras and the Grand Banks, the evidence presented in Figure 1 on the whole supports the newer conception of turbulence. It is apparently not necessary to depend largely on vertical mixing to explain the subsurface temperature-salinity correlation of mid-latitudes in the manner outlined at the outset of this discussion.

As explained above, the high oxygen-content of the deep water is a strong argument in support of vertical turbulence. No doubt both processes are working together and a great advance in our understanding of the circulation-problem will be made when the coefficients of vertical and lateral mixing can be approximately known for different degrees of stability and for currents of various strength. Until that day comes, it will probably be a mistake to favor either one or the other of these mixing processes.

As has already been indicated, provided the coefficient of lateral turbulence is assumed to be sufficiently large, it is not necessary to call on mass lateral movements at mid-depths to explain the observed salinity-anomalies. However, in this case it is necessary to assume a relatively deep current-system for the main anticyclonic eddy surrounding the Sargasso Sea. If the waters at depths near the layer of minimum oxygen are nearly motionless, there will exist only small frictional forces to cause the isopicnal mixing. Thus, before we can determine reliable mixing coefficients, we must settle the base-plane problem. It is hoped that in the near future this question can be brought to a more satisfactory state through a program of current-meter observations.

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## *ATLANTIS* CRUISE TO THE TROPICAL NORTH ATLANTIC, JANUARY TO MARCH, 1939

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(Contribution No. 223 from the Woods Hole Oceanographic Institution)

In the winter of 1939 (January 18 to March 17) a detailed investigation of the physical structure of the tropical Atlantic waters, east of the Caribbean Sea region (to the 53rd meridian) was undertaken by the *Atlantis*. The area (Fig. 1) investigated, while hitherto practically unexplored, had been known from previous scattered observations to have representative members of all the major water mass-movements of the Atlantic circulation. In the uppermost layers of this area, circulation is dominated by the North Equatorial Current, and, extending down to depths of approximately 1000 meters, striking latitudinal transitions of oceanographic characteristics (caused by mingling of water-masses of diverse properties and origins) occur. Waters from this area entering the adjacent Caribbean Sea Region, through the passages among the Lesser Antilles, play a prominent rôle in the circulation of its upper 800 to 1000 meters.

In execution of the observational program, considerations based on existing information permitted the establishment of a network of stations designed to bring out information both on specialized and general problems. It was decided to limit depth of observations to 2000 meters, a procedure which permitted (in the allotted time) both a closer horizontal spacing of stations and a smaller vertical sampling interval. In the chart shown in Figure 1, stations occupied along the five lines were approximately 50 nautical miles apart, and vertical sampling intervals of the water-column were, for the most part, 25 meters or less for every other station; while vertical sampling intervals for the remainder of the stations varied between 50 and 100 meters. In this manner detail was obtained, permitting representation of conditions with but little interpolation, such as has not heretofore been done in the ocean-basins.

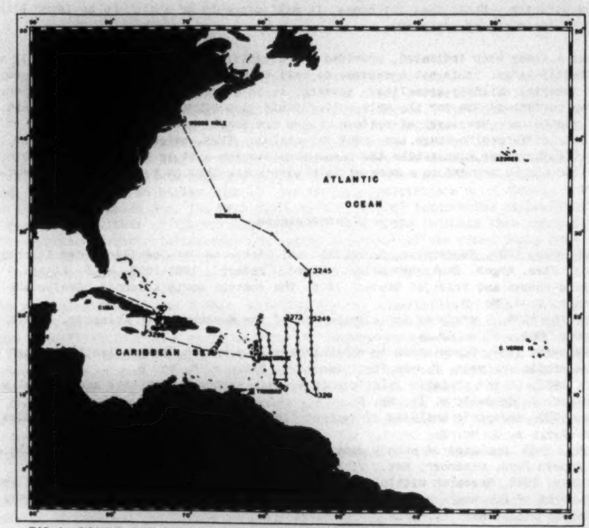

FIG. 1—ROUTE AND OCEANOGRAPHIC STATIONS OF "ATLANTIS" CRUISE TO TROPICAL NORTH ATLANTIC; BERMUDA TO HAVANA, CUBA, JANUARY TO MARCH, 1939

In presenting this brief resumé of preliminary results of the physical oceanography of this area, references concerning highly controversial subjects are dispensed with, and the procedure follows broad general outlines of generally accepted features of the Atlantic circulation. The discussion concerns only the properties of the upper 2000 meters (approximately 40 per cent of the mean depth of the area), but within this part of the water-column are found (in addition to the circulation-features of the upper layers) evidences of the presence of two of the five great water-masses which comprise a predominant part of the Atlantic circulation. The structural situation of the water-masses is illustrated by vertical distributions of salinity and oxygen (Stations 3246, 3250, and 3260) at the northern and southern extremities of the most easterly section (Fig. 2). Thus, at approximately 150 meters' depth the vertical salinity-distribution shows a well-developed maxima (diminishing in concentration from north to south), apparently representing the nucleus of water derived from surface-reservoirs of high salinity in the subtropics which later plays a prominent rôle in the Caribbean circulation.

Points of inflection, such as this, which mark maxima or minima concentrations in vertical distribution of oceanographic characteristics, may be used to analyze certain circulation-features of the ocean, and, in recent years, this type of analysis has been given prominence by the Berlin School of oceanographers in tracing water-movements over vast oceanic areas. However, when one is concerned with space-variations in concentration of maxima or minima in restricted and relatively small areas (such as the one under consideration) attention must be given to the fact that, for any observation on an inflection-point, the chances of obtaining the correct value of its concentration will primarily depend on the vertical gradients in its immediate vicinity as well as on the vertical sampling interval. Thus, in the case of the salinity-maxima in this area, the largest vertical salinity-gradients calculated in its immediate vicinity were 0.03 per mill to 0.04 per mill per meter, so that failure to sample the maximum point by, say, ten meters would cause a discrepancy ranging from 0.3 per mill to 0.4 per mill lower than its actual salinity-concentration. Thus, in drawing up the pattern of horizontal distribution of salinity-maxima in the area (Fig. 3), this consideration has been made and positions of the isohalines were primarily determined from observations of maximum salinity-concentrations where the sampling was most detailed; the dotted isohalines within the Caribbean Sea Region are based on Atlantis observations from 1937. A number of variations of this pattern may be obtained, but that shown in Figure 3 appears to be reasonable.

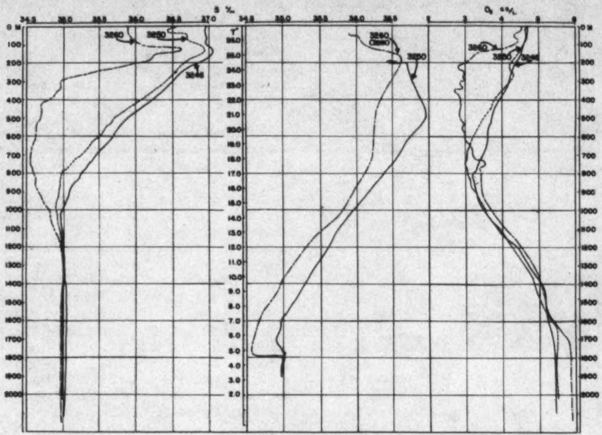

FIG. 2—VERTICAL DISTRIBUTIONS, SALINITY AND OXYGEN, "ATLANTIS" STATIONS 3246 (24° 24' N, 53° 40' W), 3250 (19° 16' N, 53° 30' W), AND 3260 (10° 58' N, 52° 56' W), AND TEMPERATURE-SALINITY RELATIONSHIPS FOR STATIONS 3250 AND 3260 [COMPOSITE CURVE ALSO BASED ON OBSERVATIONS FROM STATION 3261]

Current-arrows in Figure 3 indicate the general direction of drift (according to Montgomery's analysis [R. B. Montgomery, Papers Phys. Oceanogr. Met., v. 6, No. 2, 1938]), slight modifications having been made to conform to Atlantis records of navigation. The source of water-masses characterized by salinity-maxima, being chiefly in the subtropical surface-layer just northeast of the area investigated, may be considered as moving in an approximately west and southwest direction as the northern part of the North Equatorial Current. The concentration of salinity-maxima decreases along the route, by vertical and lateral mixing, and finally the water-mass enters the Caribbean Sea Region through the passages among the Lesser Antilles, chiefly north of latitude 15°. In the vicinity of latitude 15° and longitude 60° there would appear to be a recurving of this current, which is the source of the Equatorial counter-current. Such a recurving of the salt branch of the North Equatorial Current, just east of the Lesser Antilles, has been suggested previously, and the presence of a strong easterly surface-current in the southern part of the area is supported by Atlantis records of navigation. Between the salt northern branch of the Equatorial Current and the less-salt counter Equatorial Current, the low concentrations of maximum salinities near latitude 14° in longitude 53° (Station 3256) may indicate a westward intrusion of a "fresh tongue of the North Equatorial Current" carrying less salt water from the African coast.

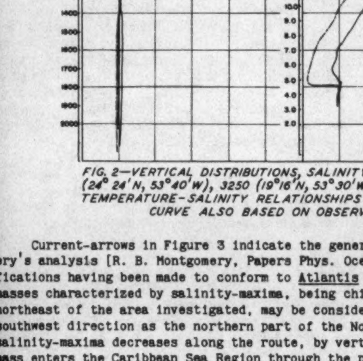

FIG. 3—PROBABLE SPACE-VARIATION IN CONCENTRATION PRINCIPAL SALINITY MAXIMA IN AREA OF INVESTIGATION [DASHED LINES WITHIN CARIBBEAN REGION BASED ON "ATLANTIS" OBSERVATIONS OF 1937]

This conception of the current-system in the upper levels of the area investigated is not in complete agreement with the conception of Defant [Albert Defant, Wiss. Ergeb. Deutschen Atlant. Exped. "Meteor" 1925-1927, v. 6, pt. I, 1936], who, in particular, places the origin of the Equatorial counter-current farther east (36° west to 44° west), outside the geographical limits of the area investigated, and who also does not consider the less saline band of water north of the so-called counter-current as a part of the North Equatorial Current. The preliminary analysis of these new data in no way invalidates Defant's conception, although the records of navigation appear to throw some support toward the other view-point, particularly as regards the counter-current.

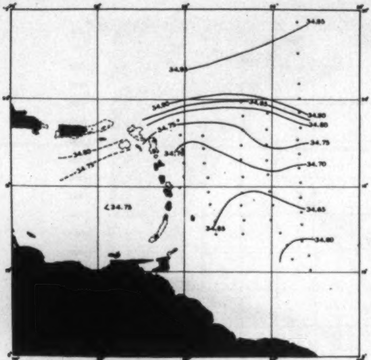

FIG. 4—PROBABLE SPACE-VARIATION IN CONCENTRATION OF MID-DEPTH MINIMA OF SALINITY

In the water at mid-depths, between approximately 750 and 1000 meters, vertical salinity-distribution (Fig. 2) shows a second point of inflection, marking an intermediate minimum of salinity-concentration, presumably representing relatively low-saline water of subantarctic origin, which has moved northward into the North Atlantic (subantarctic intermediate layer) [see Georg Wüst, Wiss. Ergeb. Deutschen Atlant. Exped. "Meteor" 1925-1927, v. 6, pt. I, 1935]. From south to north the concentration of this minimum point increases (Stations 3260 to 3246) and sinks deeper; at Station 3246 it has nearly disappeared, indicating that this latitude represents the northern limit of penetration of subantarctic water, although in the Caribbean Sea Region the mid-depth salinity-minimum is found everywhere and may be easily traced out through the Straits of Florida.

The pattern of space-variations of intermediate salinity-minima (Fig. 4) in the region investigated (mean depth = 813 meters) is more easily drawn up than that for the salinity-maxima, chiefly because smaller vertical salinity-gradients in its immediate vicinity allow more precise determinations of concentration. Outspreading of the water-masses so identified is towards the north and northwest. North of latitude 20° the subantarctic water is so diluted as to be scarcely recognizable (less than five per cent of the original water-mass is present); the main drift appears to be through the deeper passages among the Lesser Antilles, where it plays an important rôle in the Caribbean circulation. Within the Caribbean Region itself [H. R. Seiwell, Papers Phys. Oceanogr. Met., v. 6, No. 1, 1938], earlier observations have shown that, at the eastern end, the lowest intermediate salinity-value of 34.67 per mill increased along the route of the Caribbean Drift through the Caribbean and Cayman seas, the Yucatan Channel, and into the Straits of Florida (where the lowest minimum value encountered was 34.88 per mill).

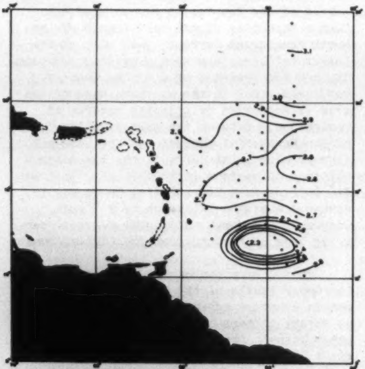

FIG. 5—PROBABLE SPACE-VARIATION IN CONCENTRATION OF PRINCIPAL MINIMA OF OXYGEN

Between the two water-masses, identified by maxima and minima of salinity, lies the principal minimum of oxygen-concentration at a mean depth of 516 meters (Fig. 2). Consideration of this characteristic is significant in physical oceanographical studies because of the ever present question: Does it or does it not identify a layer of practically motionless water? The former view adopted by certain of the Berlin School of oceanographers has led Defant [ibid.] to conclude that for the tropical Atlantic a motionless, or relatively slowly moving layer at mid-depths (characterized by the principal minimum of oxygen-concentration separates the oceanic troposphere (containing the principal salinity-maxima) from the deeper lying stratosphere (containing the intermediate salinity-minima). And, the adoption of this suggestion, when other possibilities exist [see H. R. Seiwell, Papers Phys. Oceanogr. Met., v. 5, No. 3, 1937], places definite restrictions on the derived circulation, particularly when use is made of geographical variations in dynamic topography to estimate horizontal current-patterns.

In the region investigated, curves for the vertical distribution of oxygen at northern and southern extremities of the most easterly section (Fig. 2) show significant latitudinal variations in oxygen-content; the minimum concentration of oxygen declines in value from north to south as its depth diminishes from approximately 800 to 350 meters. Thus, at mid-depths, the water in the southern part of the region has been far more depleted of its dissolved oxygen than has that occupying the northern part; at Station 3260 (at southern end of the area), for instance, there is but little difference in oxygen-content of the water-column between 200 and 600 meters, whereas at Station 3246 the minimum of oxygen is well marked out, and comparing vertical salinity- and oxygen-distributions at mid-depths, low oxygen-content in the south is seen to be associated with relatively low-saline water which has moved in from the region to the south.

The probable pattern of geographic distribution of minimum oxygen-values in the region investigated, as represented by Figure 5, shows the general north-south decline in concentration; two centers of low values occur, one represented by Stations 3253 and 3254 in the east central part and the other by Stations 3263, 3264, and 3282 in the southern part of the area. Thus, whatever water poorest in oxygen from mid-depths in the southeastern part of the area (associated with lower salinities) moves westward, toward the Caribbean basins, undergoes some rejuvenation by mixing with oxygen-richer (higher saline) water which has entered the area from the north.

Further examination of vertical salinity-distribution (Fig. 2) shows that everywhere in the area investigated, generally between depths of 1250 and 1350 meters, a third point of inflection marks out a secondary salinity-maximum. This characteristic, less prominent than the others, had a concentration-range (for the entire area) of only 34.99 per mill to 35.03 per mill, about 4 per cent of the intermediate salinity-minimum range. Its possible significance is that it apparently indicates the spreading out of the upper part of the North Atlantic Deep Current [see Wüst, ibid.] carrying relatively higher saline water southward to play a prominent rôle in the circulation of the Atlantic. The general direction of motion is approximately opposite to that of the layer identified by an intermediate salinity-minimum (it plays no obvious part in the circulation within the Caribbean Sea Region).

Diversity in character of water-masses entering into the circulation of the area investigated may further be brought out in sharp contrast by comparison of temperature-salinity relationships for two positions, 500 miles apart (Stations 3250 and 3260), along the most easterly section (Fig. 2). In the south, not only were salinities lower over the entire upper 2000 meters of the water-column, but, for any particular temperature, the associated salinity may be as much as 0.7 per mill less than that further north; and, this, coupled with extreme differences in content of dissolved oxygen, clearly shows that water-masses making up the circulation of this region are drawn from widely separated regions. As the water-masses of the upper 1000 meters or so move in a general westerly direction they combine so as to lose still more of their original identities so that within the Caribbean itself more uniform patterns are encountered.

In addition to the regular oceanographic observations, six stations were occupied for internal-wave observations (Fig. 1), five of which were made while the vessel was anchored (over depths of 5000 meters or more); each completed station consisted of 28 to 32 lowerings of 18 samples each, between surface and 1000 to 1100 meters, taken over approximately 25-hour periods. The average time between completed samplings of this water-column was 56.2 minutes. The sixth station (3299), worked while the vessel was drifting, was discontinued after 11 hours because of unfavorable weather.

In every case, large time-variations of oceanographic properties characterized observations at fixed depths (as measured from the sea-surface) and temperature-variations illustrate the magnitude of the phenomenon. During the five 25-hour observation-periods, maximum amounts of temperature-variations at standard depths ranged from 1°.19 to 2°.25 and the minimum variations from 0°.13 to 0°.31; the most frequent amount of temperature-variation at fixed depths during the 25-hour intervals was from 0°.6 to 0°.7. Thus, for instance, at Station 3245 (25° 32' north and 53° 45' west), the following ranges of temperatures were observed between $2^h 51^m$, January 23, and $4^h 45^m$, January 24, 1939 (GCT):

| Depth | Temperature-range | Depth | Temperature-range |
|---|---|---|---|
| | ° | | ° |
| 0 | 0.60 | 600 | 0.63 |
| 100 | 1.31 | 700 | 0.63 |
| 150 | 2.35 | 800 | 0.66 |
| 200 | 0.32 | 900 | 0.32 |
| 300 | 0.36 | 1000 | 0.50 |
| 400 | 0.45 | 1100 | 0.24 |
| 500 | 0.57 | | |

Previous evidence has indicated that variations of oceanographic characteristics (such as temperature) result from vertical displacements of the water-column, in which case temperature-variations at Station 3245 are related to vertical displacements (occurring during this time) of between 15 and 56 meters; whereas, at other stations in the series, vertical displacements of more than 75 meters are required to produce the observed time-temperature variations. Thus, since this phenomenon apparently occurs in all oceans, information of this kind is significant, not only for investigation of internal waves, but to assist in interpreting and estimating the significance of results of practical oceanographical investigations.

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## A NEW BATHYMETRIC CHART OF THE CARIBBEAN AREA

H. H. Hess

### (Abstract)

The manuscript of the full discussion of the new chart has been submitted for publication to the Section of Oceanography of the International Geophysical Union of Geodesy and Geophysics. Therefore only a brief abstract is presented here.

The chart has been published by the Hydrographic Office of the United States Navy and is obtainable from that Office. It is based primarily on soundings by 90 cruises of vessels of the United States Navy. The scale is approximately 1:2,750,000. The writer takes responsibility for the contouring.

Considering the scale of the chart, the quantity and quality of information available, and the distances from shore, the writer believes this chart represents the most accurate presentation of deep-sea topography thus far published.

Much credit should be given to the past and present hydrographers, the staff of the Hydrographic Office, and the personnel of the vessels which took the soundings for this contribution to the science of oceanography.

Princeton University,
Princeton, New Jersey

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## RESEARCH WITHIN PHYSICAL OCEANOGRAPHY AND SUBMARINE GEOLOGY AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY DURING APRIL 1938 TO APRIL 1939

H. U. Sverdrup

(Contributions from the Scripps Institution of Oceanography, New Series, No. 63)

In this report emphasis will again be placed on the activities within the fields of submarine geology and physical and chemical oceanography, although researches within the biological fields have, as previously, held an important place on the program of the Scripps Institution of Oceanography. The studies have been conducted partly by the regular staff of the Institution and partly by visiting scientists. The work in the laboratory and the compilation and discussion of field-data have been greatly facilitated by assistance obtained from the Works Progress Administration Project which during the past four years has been in continual operation at the Institution.

During the past year the program, initiated in 1935, of chemical and mechanical analyses of sediment samples in the collections of the Scripps Institution has been continued. Part of this work has been supported by a grant from the Geological Society of America to Dr. R. Revelle. One thousand and sixteen mechanical analyses by the internationally used pipette-method have been completed, together with 554 organic determinations of nitrogen, 156 determinations of calcium carbonate, 75 analyses of organic carbon, and 350 determinations of water and dissolved-salt content. H. Niederman has been in charge of the making of these analyses, and has been assisted by E. Caney, K. Heusner, and a number of Works Progress Administration laboratory technicians.

Until the end of November, 1938, the vessel E. W. Scripps was in alternate months employed in a program of geological investigation of the sea-bottom in the southern California Region.

This work also was largely supported by the Geological Society of America, and was under the direction of Dr. F. P. Shepard. The Sediment Division of the Institution cooperated in many of the phases of this investigation, particularly those involving marine sediments. One of the principal results of the work, from the point of view of the study of sediments, was the development by Dr. Shepard's assistants, R. S. Dietz and K. O. Emery, of a heavily weighted, long core tube with a specially designed nose, which has been very successfully used in the taking of cores of bottom-mud occasionally up to ten or more feet in length. A number of cores from off the California Coast between Monterey Bay and San Diego and as far west as the red-clay area west of the "continental borderland" were collected with this instrument. These are being analyzed in the sediment laboratories of the Institution.

A simple device for measuring currents close to the sea-bottom was designed during the past year by C. I. Johnson and R. Revelle, and has been extensively used. It proved possible with this instrument to measure bottom-currents in water at least 1000 meters in depth without anchoring the vessel; a series of measurements in various types of marine environments was an integral part of the geological investigations directed by Dr. Shepard. With the aid of this instrument also, R. H. Fleming and R. Revelle carried out a preliminary investigation of the effect of bottom-friction on velocity-profiles close to the sea-floor.

On the expedition to the Gulf of California, to which reference will be made later on, bottom-samples were collected at 50 of the stations occupied by the E. W. Scripps. These were mostly cores ranging in length from a few inches to more than nine feet, and in appearance from stiff brownish-gray clay taken near the mouth of the Colorado River, to loose, flocculent, green mud smelling strongly of $H_2S$, collected in the southern half of the Gulf. Most of the cores containing $H_2S$ were minutely stratified, while in the northern end of the Gulf marked textural variations in many cores reflected the shifting balance of sedimentational forces between the Colorado River and the strong tidal currents of the Gulf itself.

Over 2500 echo-soundings were taken in the Gulf; although these have not been compiled, preliminary inspection of the results shows that the southern part of the Gulf is not the gently sloping depression it might be supposed to be from published charts, but instead is very irregular, containing a series of steep ridges and deep basins and troughs, separated by probable fault-scarps.

M. L. Natland has continued during the past year his studies of foraminifera in the bottom-sediments of the west coast of North America, with special regard to the relative effects of temperature and depth on the distribution of the calcareous remains of these organisms. He is at present engaged on an intensive study of the bottom-samples from the southern California Region which are in the collections of the Institution.

Mr. LaFond has been in charge of observations made from the Scripps Institution and other piers near La Jolla in order to determine the nature of the sand-movements. Approximately 13,500 soundings have been made from these piers during the past year in order to determine the nature of the beach-profile. Systematic observations of the sand-level in front of the Institution have also been made. A recording current-meter has been in operation on the end of the pier but owing to damage caused by storms the observations cover only 270 days. A wave-recording device which will record the frequency and amplitude of the waves has been in use and records have been obtained on 64 occasions.

Averaging and plotting by months and quadrangles of sea-surface temperatures reported to the Scripps Institution by navigators of steamers in the Pacific Ocean have been continued.

The Works Progress Administration Project sponsored in 1935 by the University of California, for compiling oceanographic data reported since 1924 by navigators of vessels in the Pacific, has continued. The work is carried on in three rooms in the Long Beach Municipal Auditorium Building under the general superintendency of the Director of the Scripps Institution and is supervised by the officer (at present Lieutenant Commander T. O. Cullins) in charge of the Branch Hydrographic Office of the United States Navy at San Pedro.

After data are transferred from the coding sheets to punched cards, the cards are sent to the Washington Office for mechanical tabulation. In accordance with arrangements made with the United States Hydrographic Office, the final coding sheets of data thus compiled are filed at the Scripps Institution for use in various studies of ocean-surface conditions, in particular for investigating variations in the Japan Current. There are at present 40,500 of these sheets on file. Each sheet has space for 27 complete observations. Compilations from these on forms appropriate for the above studies were begun in the fall of 1938.

Investigations were continued of trends of air and sea surface-temperatures of the southern California area for the purpose of providing advance indications of temperature. Also investigations have been continued of cycles in the seasonal precipitation of Pacific coastal areas, and of advance indices of the probable amount of this precipitation. Interest in these projects continues as usual according to our correspondence with many individuals and representatives of various organizations.

Periodograms prepared in the Bureau of Power and Light in Los Angeles indicate that corresponding rainfall-cycles have distinctly shorter periods in the Columbia River Valley Region in Oregon and Washington than they have throughout most of California. Cycles in the San Diego Region may be badly mixed up, but this has not been investigated yet in detail. It would appear that cycle-lengths are greatly affected by local conditions. A preliminary attempt has been made by Mr. Gordon at formulating differential equations expressing a relationship of rainfall-sequences with characteristics of dominant vegetation in a region; the equations so formulated afforded possibilities, but the basis on which they were formulated probably needs considerable revision and checking with statistical studies.

McEwen's formula applied to a component of flow between two points results in a ratio of two quantities both of which seem to be subject to normal distribution of error, with rather large standard deviations. The resultant error-distribution of the ratio has no mean value. The problem of such errors has been investigated by Mr. Gordon. A function, f(v), was sought such that if v is normally distributed about a "true" value D, then f(v) would have the mean value 1/D. Such a function is uniquely given by

$$f(v) = (1/\sigma)\, e^{v^2/2\sigma^2} \int_v^\infty e^{-t^2/2\sigma^2}\, dt \cdot$$

where $\sigma^2$ is the variance of v, with the added restriction that f(v) shall be independent of D. This formula holds if D is positive; for negative D, the integration is from v to $-\infty$. This seems to be a new result.

This function f(v) not only has the mean value 1/D, but also satisfied the "law of large numbers," by a theorem due to Khintchine. Mr. Gordon is trying to develop some information on how "fast" it satisfied the law of large numbers before publishing the result.

A further difficulty concerned with the question of whether the sign of D is the same as the sign of the observation v, or the opposite of v, seems to be overcome by means of some polynomial approximations.

Two contour-maps have been prepared, one of the Santa Barbara Region, 34° 10' to 34° 30' north and 119° 14' to 119° 50' west on a sheet 54 by 72 inches, and one of the Santa Monica Region, 33° 40' to 34° 10' north and 118° 20' to 118° 45' west on a sheet 54 by 72 inches. Preliminary work required for a third map of the San Diego Region has been done. A topographic and ocean-floor classification map has been completed of the region from Point Conception to the Mexican Border, 32° 20' to 34° 00' north and 117° 00' to 120° 00' west on a sheet 36 by 40 inches.

Dr. G. F. McEwen has continued work on various kinds of computational methods for determining the vertical velocity and turbulence in the ocean. Total numerical applications of methods thus developed are being made.

Also, researches on theories of the dispersion of material in suspension in the ocean were begun by McEwen in December, 1938, with particular reference to developing practicable computational procedures applicable to the vertical and offshore dispersion of slowly settling silt from near-shore regions.

Mr. Gordon has assisted in both of the above undertakings by checking the mathematical work involved in deriving various formulas and by his studies on certain problems of integration and of the estimation of errors of certain approximate methods.

During the past 12 months most of the work in the Chemistry Division has consisted in making the chemical determinations in connection with the various oceanographic cruises.

During June and July, 1938, Dr. W. L. Burdick of Sacramento Junior College made an intensive study of various methods for determing iodine in sea-water, and with one of these methods he obtained results that agree well with the most reliable results previously published.

In last year's report it was stated that in 1938 six cruises would be made with the Institution's vessel, the E. W. Scripps, in order to cover the area which had been examined in 1937 in cooperation with the California State Division of Fish and Game. The planned cruises were undertaken but, owing to unfavorable weather, some stations had to be omitted on Cruises I, II, and V. On Cruise II, owing to storms and to the fact that time was not available for extending the work over a longer period, only two lines of stations were completed. On each cruise temperature and water-samples were obtained at approximately 30 stations, but on all except the first the studies were limited to a depth of 600 meters because it had previously been found that conditions were very uniform below that level. The oxygen-content of the water was determined on all samples and on the first three cruises determinations of phosphate were made.

At all stations quantitative plankton-catches were made at seven depths between the surface and 60 meters, and on all cruises except the first one vertical hauls for zooplankton were made between 200 meters and the surface. On Cruise IV measurements of the transparency of the water between the surface and 60 meters were conducted by Dr. R. T. Young, Jr., at about 20 stations, using a Pettersson's transparency-meter which had been built at the Scripps Institution. All data pertaining to physical oceanography have been compiled under the supervision of Dr. R. H. Fleming. Dynamic calculations have been completed, final tables and a number of charts have been prepared. Tables and charts with a brief accompanying text will shortly be submitted for publication in the Institution's Technical Bulletin.

At this time attention will be drawn only to the character of the surface-currents as derived from charts of the dynamic topography of the surface relative to the 500-decibar surface. These charts show that in 1938 the character of the currents changed throughout the year according to a fairly well-defined pattern. During Cruise I, from February 15-25 (Fig. 1), the offshore current was broken up by a series of large eddies. The topography indicates a general transport towards the southeast, but in the southwestern part of the area there was a considerable influx of water from offshore. A well-defined current flowed towards the north past Point Conception. In the southeastern part of the area the counter-current turned around and near the coast was directed towards the south.

Conditions during Cruise II, April 8 to 12 (Fig. 2). appear extremely simple, but this may be due entirely to lack of observations on two of the lines. However, the observations show no indication of the counter-current which on Cruise I was clearly demonstrated by the data from the northern lines. The general flow was directed towards the southeast. The conspicuous change can be ascribed to the effect of upwelling which, according to the experience of 1937, probably began at the end of March.

On Cruise III, from June 7 to 16 (Fig. 3), the effect of upwelling is very clearly demonstrated by the topography of the surface. A narrow band of high current-velocity separates the lighter offshore water from the colder and heavier upwelled water near the coast. The eddy in the vicinity of San Nicolas Island which was conspicuously present in May, 1937, is found on this chart, and the counter-current which turns around near the coast is also seen. On the whole, there is a striking similarity between the conditions encountered in June, 1938, and those found in May, 1937.

The surface-topography on Cruise IV, August 16 to 26 (Fig. 4), shows an extremely irregular pattern of flow in the offshore area where eddies rotating in different directions appear to be present. In the southeastern corner of the area a conspicuous inflow of water from the south took place.

On Cruise V, from October 26 to November 5 (Fig. 5), the general flow to the southeast dominates, but offshore several eddies are present and inshore the counter-current flows to the north along the greater portion of the coast.

On Cruise VI, December 9 to 18 (Fig. 6), conditions were encountered which bear considerable similarity to those which were present from February 15 to 25, indicating that there may be a rather clearly-defined pattern in the annual cycle. Offshore there was a general southeasterly flow separated from the counter-current near the coast by a well-defined trough. The counter-current again extended northward beyond Point Conception, and in the southwestern part there was a large-scale inflow of water similar to that encountered on Cruise I.

Although it is somewhat premature to generalize, it may be said that an inshore counter-current flowing in the opposite direction of the general current off the coast appears to be the normal phenomenon which is present during periods of variable winds. During the time of the year when the northwest winds dominate, upwelling takes place and as a consequence the counter-current

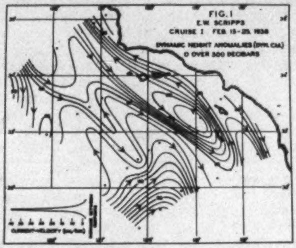
FIG. 1
E.W. SCRIPPS
CRUISE I FEB 15-25, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

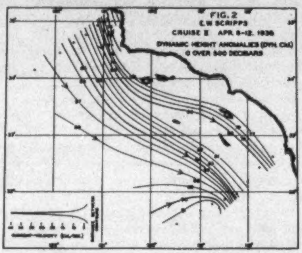
FIG. 2
E.W. SCRIPPS
CRUISE II APR. 5-12, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

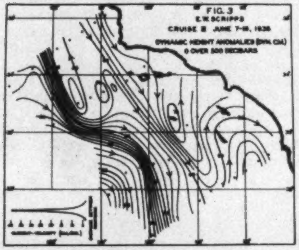
FIG. 3
E.W. SCRIPPS
CRUISE III JUNE 7-16, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

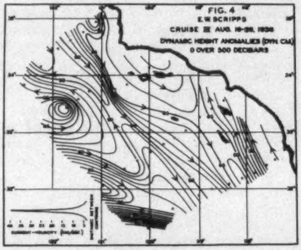
FIG. 4
E.W. SCRIPPS
CRUISE IV AUG. 16-28, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

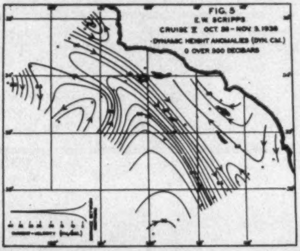
FIG. 5
E.W. SCRIPPS
CRUISE V OCT. 26 - NOV 3, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

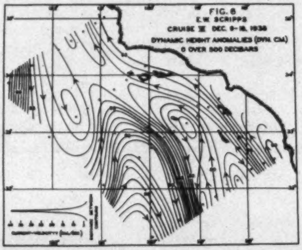
FIG. 6
E.W. SCRIPPS
CRUISE VI DEC. 9-18, 1938
DYNAMIC HEIGHT ANOMALIES (DYN. CM.)
0 OVER 500 DECIBARS

disappears owing to the accumulation of cold upwelled water near the coast. When the northwesterly winds stop blowing the counter-current is again gradually developed and reaches its full strength during the winter months.

The results of these cruises have found an interesting application by E. C. LaFond in his examination of the relation between surface-temperatures and sea-level, to which reference was made in last year's report. By extrapolating the topography of the surface to the coast it is possible to determine the changes in sea-level which should be expected if they were due entirely to changes in the density of the coastal waters above the 500-decibar surface. A comparison with recorded variations of sea-level clearly shows that these are in perfect agreement with the variations obtained from our charts. These results greatly strengthen the opinion which was expressed in last year's report, namely, that records of sea-level can be used for the study of coastal currents.

From February 5 to March 31, 1939, the E. W. Scripps undertook a cruise to the Gulf of California. Actual work in the Gulf was conducted between February 19 and March 20. The scientific work was in charge of E. G. Moberg until March 8, and in charge of H. U. Sverdrup after that date.

It was planned to run a number of lines across the Gulf, to occupy stations along these lines at intervals of 15 to 20 miles, and to collect the same type of data which were collected on the cruises of 1938, except that here it would be attempted to obtain samples at standard depths between the surface and the bottom. In addition, soundings by sonic-depth finder should be made at frequent intervals and bottom-samples secured at most stations. The plans were carried out in all details and, in addition, favorable weather-conditions made it possible to undertake detailed soundings of and to occupy two stations in the channel between the island of Angel de la Guardia and the Peninsula.

It is not yet possible to report on the results of the cruise but the temperature-distribution in the surface-layers reveals several features of interest. At a depth of ten meters the highest temperatures, up to 21°, were found between Cape San Lucas and Mazatlan. From this line the temperature decreases towards the north, reaching a minimum of less than 14°.5 in the latitude of Tiburon Island. Further north, in the shallow inner portion of the Gulf, temperatures ranging between 14°.5 and 15°.5 were found. This temperature-distribution must be due partly to the northwest winds which prevail in January and February and transport the warm surface-waters out of the Gulf. The low temperatures near Tiburon Island must be due to upwelling. In the inner portion the vertical distribution of temperature indicates that there complete mixing from the surface to the bottom takes place in winter when the density of the upper layers is decreased by cooling and evaporation. It thus appears that in winter the circulation in the Gulf of California is entirely different from that of the Red Sea with which the Gulf is comparable both as to size and geographical location.

On the Gulf cruise a considerable amount of chemical work was undertaken, including determinations of pH and base, at a number of stations. The buffer-mechanism and calcium-to-chloride ratio in various parts of the Gulf is now being examined. It is thought that, owing to the inflow of water from the Colorado River, the water in the Gulf may differ from that of the open ocean with respect to both of these properties.

I take particular pleasure in reporting that the Hydrographic Office of the United States Navy arranged that in March, 1939, the U.S.S. Bushnell should occupy eight oceanographic stations en route from Panama to San Diego and eight more stations between San Diego and Pearl Harbor, Hawaii. Mr. LaFond went to Panama and accompanied the Bushnell on its journey to San Diego, during which the eight stations were occupied. Five of these were located off the entrance to the Gulf of California and will, thus, supplement the work conducted by the E. W. Scripps in the Gulf. Oxygen-determinations were made on board on all samples and salinity-determinations are now being made at the Scripps Institution.

In conclusion I wish again to emphasize that the present report covers only that part of the activities of the Scripps Institution which can be assumed to be of greater interest to the American Geophysical Union.

Scripps Institution of Oceanography,
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La Jolla, California

## AMERICAN GEOPHYSICAL UNION

### Twentieth Annual Meeting

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## SECTION OF VOLCANOLOGY

Washington, D. C.
April 26, 1939

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## THE TUSCAN SOFFIONI: A REVIEW

E. T. Allen

(Abstract)

In geological, geophysical, and chemical aspects the soffioni are quite similar to hydrothermal phenomena in the western United States, particularly in Sonoma County, California. Though described as recently as the last decade as "an entirely distinct class of pseudovolcanic manifestations," the soffioni and lagoni are really fumaroles and spouting hot-springs distinguished by degree of activity rather than by difference in kind. Their association in Tuscany with fissures, with older intrusive rocks, with veins of copper, lead, and antimony, as well as the high temperature of the steam and other characteristic gases, proclaims their magmatic origin. These phenomena have a peculiar claim to the interest of volcanologists and geophysicists, (1) because Tuscany is the only place in the world where volcanic steam has been successfully utilized on a commercial scale (the credit for this belongs to Prince Piero Ginori Conti); (2) because this is probably the only active hydrothermal area where the volcanic products, boric acid, carbon dioxide, and ammonia, have been systematically and continuously recovered; (3) because of the extensive cooperation between science and industry in the exploitation of the soffioni. Besides an immense amount of work involving engineering, physics, and chemistry, drilling for steam has added much to geological information. Systematic meteorological observations are now in progress, an exact series of topographic levels has been determined, and magnetic and gravimetric surveys have been made, but important deductions from them remain for the future.

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## EXTREME FRACTIONAL CRYSTALLIZATION OF A BASALTIC MAGMA: THE STILLWATER IGNEOUS COMPLEX

H. H. Hess

(Abstract)

An abstract is here presented of the writer's investigations since 1935. This research is part of a large project involving the detailed study of the Stillwater Complex being carried out by Peoples, Howland, Sampson, and the writer, which will be prepared for publication during 1939. The investigations of the writer's colleagues started in 1930. It was known in 1935 that the Stillwater Complex was a huge concordant sheet or lopolith which had differentiated by settling of crystals, layer upon layer. This sheet has been turned up on end and bevelled across by erosion. The floor is exposed and approximately 17,000 feet of banded rocks above the floor, but the top of the Complex and roof are covered by Paleozoics.

If the Complex had been formed by settling of crystals, layer upon layer, it seemed to the writer that valuable information as to the course of crystallization of the magma could be obtained by sampling the Complex at small intervals from the floor to the highest exposed horizon, and determining the composition of the minerals in each specimen. This was done for some 300 specimens. The mineralogy of the Complex is exceedingly simple, consisting essentially of four minerals: (1) Plagioclase; (2) orthopyroxene; (3) clinopyroxene; and (4) olivine. Accessory minerals are almost entirely lacking, though some chromite and sulfides are found at certain horizons, and a little interstitial micropegmatite (quartz-orthoclase).

A border facies ("chill facies") is present along the floor which serves to indicate the composition of the original magma. The mineral composition at various levels can thus be compared to the norm of the border facies. This norm is also of unusually simple composition, consisting of 98 per cent pyroxene and plagioclase. The rock is very low in volatile constituents and has little $TiO_2$, $Fe_2O$ , etc.

The normative plagioclase is $An_{68\ 1/2}$. The [En/(En + Fs)]-ratio is 59 1/2. The [Ortho-Px/(Ortho-Px + Clino-Px)]-ratio is 0.75. The norm shows 98 per cent pyroxene and plagioclase of which 56 per cent is the latter.

The following variations were found in the minerals present. (Besides the settled crystals of which these rocks are dominantly composed, a certain amount of material has crystallized from the interstitial liquid between such crystals; thus, as in the case of orthopyroxene, two generations of crystals may be present.)

Table 1

| Mineral | Variation |
|---|---|
| Olivine | $Fo_{88}$ to $Fo_{85}$ (ultramafic zone) |
| Second generation interstitial | $Fo_{82}$ to $Fo_{72}$ (high in complex) |
| Orthopyroxene | $En_{86}$ to $En_{70}$ |
| Late stage interstitial | $En_{74}$ to $En_{61}$ |
| Plagioclase | $An_{86}$ to $An_{61}$ |
| Clinopyroxeme | $Di^{*}_{89}$ to $Di_{79}$ |

*Di = Diopside; the pyroxeme is essentially a member of the diopside-hedenbergite series, but may contain up to 25 per cent dissolved clinoenstatite-clinoferrosilite.

The mineral-variation curves show no sharp breaks, indicating that the bulk of the magma was injected at the initial epoch of intrusion, and that later additions, if any, were too small in bulk to materially change the composition or temperature of the magma during the entire course of crystallization.

The curves show irregular small fluctuations up and down, which the writer would correlate with the rate of accumulation of crystals. Where accumulation is slow, diffusion of material from the magma above into and out of the interstitial liquid in the crystal mush on the floor will tend to allow crystallization in it of minerals having almost exactly the same composition as the settled crystals. If, however, accumulation is faster, the time necessary for diffusion before the mush becomes a solid rock is too short; thus somewhat more iron-rich and soda-rich pyroxenes and plagioclases, respectively, are formed, since the interstitial liquid is much richer in iron and soda than the settled crystals.

Investigations reported in the "Transactions" for 1938 indicated that the thickness of crystal mush on the floor at any one time was in the neighborhood of ten feet. Interpolations from Lovering's data on the rate of cooling (and hence crystallization) of a thick sheet indicate that this crystal mush must have remained in that state for a period of from 30 to 300 years. Bowen's figures for rates of diffusion of certain silicates indicate that this would be sufficient time for diffusion to be operative.

In comparing the mineral-variation curves, it is found that the olivine and orthopyroxene of the ultramafic zone fluctuate together, and that the orthopyroxene and clinopyroxene higher in the Complex do likewise. There is a suggestion that the fluctuations in the plagioclases corresponding to fluctuations of the orthopyroxenes occur at a slightly higher horizon, perhaps as a result of the relatively slower settling of plagioclase.

The occurrence of interstitial olivine at a high level in the Complex after a thick olivine-free zone is somewhat of a puzzle. These olivine-bearing rocks invariably occur above and below thick anorthosite bands. A suggestion as to the course of crystallization which produced them may be found in Bowen's and Schairer's work on $MgO-FeO-SiO_2$.

It was noted that the border facies was just saturated with silica and that it contained neither quartz nor olivine in appreciable amount. Olivine did crystallize in large quantities early in the course of crystallization. As might be expected from this, interstitial micropegmatite makes its appearance near the top of the exposed section, and the inference may be drawn that a large amount of this material probably exists in the covered zone.

The normative plagioclase of the border facies is $An_{68\ 1/2}$. The first settled plagioclase crystals found in the section have a composition of $An_{86}$, which closely approximates the plagioclase which would be in equilibrium with a liquid of $An_{68\ 1/2}$. Thus it appears that plagioclase settled rather than rose in this particular magma from the start of crystallization of that mineral.

On the whole, and with a large number of the minor details as yet unexplained, the course of crystallization indicated, and the resulting differentiation beautifully substantiates, conclusions from geochemical investigations by Bowen and others. No doubt the low volatile content and relative simplicity of magma make the Stillwater Complex an ideal example to compare with such geochemical investigations. The results may thus be said to be a direct confirmation in naturally occurring, normal, mafic, plutonic, igneous rocks of the deductions arrived at by Bowen and others, as to the course of crystallization and differentiation of such a magma with crystal sorting.

The writer wishes to take this opportunity to express his indebtedness to his colleagues, and in particular to Dr. Peoples, on whose firm foundation of Stillwater geology this mineralogical investigation was based.

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Princeton, N. J.

## BORABORA LAVAS

J. T. Stark and A. L. Howland

### (Abstract)

Borabora, one of the Society Islands, represents three eroded remnants of a once more extensive volcano. Quaquaversal dips of the lava-flows and hundreds of radially striking, basaltic dikes locate the crater in the submerged lagoon between the large eastern island and the down-faulted remnant of the western crater-rim. Ellipsoidal structures of subaerial origin in the lavas extend from sea-level to nearly 2500 feet and are believed due to rapid vesiculation and consequent billowing of the lavas. The lavas and dikes show a limited range of composition ranging from oceanites to olivine-poor basalts. The only significant differentiation, other than concentration of olivine, is in a large dike in which the center shows a concentration of alkalies. The limited variation in composition is in contrast to the occurrence of trachytic and syenitic types on Tahiti and Moorea.

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## PRESSURE-RIDGES AND COLLAPSE-DEPRESSIONS ON THE McCARTYS BASALT FLOW, NEW MEXICO

Robert L. Nichols

### (Abstract)

In an area approximately two miles long, near the terminus of the McCartys Flow, there are about 100 collapse-depressions. The largest depression is nearly a mile long and in places as much as 300 feet wide, whereas the smallest is only a few feet in diameter. They may be as much as 28 feet deep. They are formed by the collapse of the roofs of lava-tunnels.

Analysis of the probable strength of the roofs of lava-tunnels indicates that they owe their origin not to the collapse of one large tunnel but to the partial collapse of several small tunnels. That the crust had considerable thickness at the time of the withdrawal of the lava from the tubes is indicated by the following: First, the size of the collapsed blocks in the depressions; second, the roofs of the tunnels had considerable strength and therefore thickness as is indicated by the fact that they are only partially collapsed; and third, a cave was found in the Flow whose present roof is eight feet thick.

Although many of the depressions may have been formed quite recently, in some cases, however, collapse occurred while liquid lava was still present and when the under side of the crust was still soft and plastic.

Calculation shows that the drainage of approximately 80,000,000 cubic feet of lava was responsible for the formation of the tubes, a volume equal to about half a mile of the Flow.

On the last mile of the Flow pressure-ridges are very common. The shortest are only 130 feet long while the longest are more than 1200 feet. They are from 10 to 25 feet high and as much as 100 feet wide. In transverse cross-section the sides of the pressure-ridges are steep, reminding one of the gable of a house or the cross-section of a broken anticline. They have a medial crack running along the crest of the ridge which may be as much as 15 feet in width but which is usually much less. They are almost without exception lined up parallel with the Flow and they are in general close to its margin.

That these pressure-ridges were formed when liquid lava was still present below the crust is proved by the fact that some of the medial cracks are filled in part with secondary lava which

welled up into them after the formation of the ridges. Analysis shows that the crust must have been several feet thick when the pressure-ridges first began to form and that five to ten feet is a good figure for the maximum total transverse shortening of the crust involved in their formation.

Several theories for the origin of pressure-ridges have been advanced. Israel C. Russell suggested that those of the Snake River Plains were produced by lateral pressure acting on the surface-portion of the lava-flows, arising from the viscous drag of slowly moving sub-crustal lava. Lateral pressure was undoubtedly responsible for the McCartys Flow pressure-ridges but that this pressure was not the result of the viscous drag on the crust of slowly moving sub-crustal lava is indicated by the following: First, it seems unlikely that the sub-crustal drag of viscous lava would be strong enough to break and buckle up a crust several feet thick; and second, if a viscous sub-crustal drag was the force that formed these pressure-ridges, one would expect them to be oriented in general transverse to the direction of the flow and not parallel to it.

It is suggested that prior to the formation of the ridges the McCartys Flow, in the area where these ridges are found, instead of having a flat top from margin to margin, was domed. The collapse of such a dome following the withdrawal of lava from beneath it would generate great compressional forces near the margin of the Flow. Calculation shows that the collapse of a dome 65 feet high might have formed these pressure-ridges.

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## GROOVED LAVA IN THE CROSS-SECTION OF BIG CRATERS, IDAHO

Robert L. Nichols and Charles E. Stearns

### (Abstract)

The surfaces of many thin flows interbedded with the pyroclastic material of Big Craters, Craters of the Moon National Monument, Idaho, are grooved, striated, pock-marked, and covered with shark's tooth projections.

These features in most cases resulted from the falling of blocks, bombs, and lapilli onto the surfaces of still molten flows. They indicate that there were periods during the growth of the cone when there was simultaneous extrusion of lava and pyroclastic material.

However, one outcrop of grooved lava was found which resulted not from the bombardment of a molten flow by pyroclastics but rather from the over-riding of a viscous flow by solid crustal material derived either from another part of the same flow or from a different flow.

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## SOME FEATURES OF THE LIVINGSTON FORMATION NEAR NYE, MONTANA

J. S. Vhay

(Published with the approval of the Director, U. S. Geological Survey)

### Introduction

The Livingston Formation is a series of pyroclastic rocks several thousand feet thick cropping out on the north side of the Beartooth Mountains. These pyroclastic rocks grade laterally into the Claggett, Judith River, Bearpaw, and Lennep formations of the Montana Group, according to Stone and Calvert [see 1 of references at end of paper], showing that they were being deposited during much of Montana time; they are therefore of Upper Cretaceous age and antedate the Laramide orogeny.

The purpose of this paper is to describe briefly several significant features of the Formation where it is exposed in the Nye No. 2 Quadrangle (Fig. 1) along the southeast edge of its outcrop. It is concluded that much of the Formation was formed by mudflows, and that certain chloritized beds were deposited by hot mudflows.

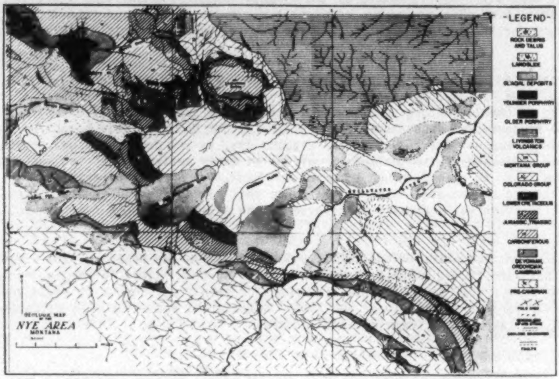


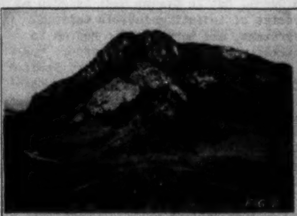
FIG. 1—GEOLOGIC MAP OF A PART OF NYE NO. 2 QUADRANGLE, MONTANA; HORIZONTAL RULING IN UPPER RIGHT-HAND CORNER SHOWS DISTRIBUTION OF LIVINGSTON FORMATION [TAKEN, WITH SOME CHANGES, FROM UNPUBLISHED Ph.D. THESIS, "THE GEOLOGY OF A PART OF THE BEARTOOTH MOUNTAIN FRONT NEAR NYE, MONTANA", BY J.S. VHAY, PRINCETON UNIVERSITY, 1934]

The Livingston Formation underlies a rolling grassy upland, dissected by numerous deep canyons and gullies. Exposures are good at the edges of the upland area and along the gullies. At several places the transitional contact with the lower part of the Montana Group is well exposed; above the Eagle Formation, which is at the base of the Montana Group, the sandstones contain more and more volcanic material until [somewhere in the Claggett (?) Formation] true volcanic conglomerates come in, and these give way above to the typical pyroclastic rocks. At least a thousand feet of the Livingston Formation is exposed here, but its upper limits lie outside the area.

Texturally, the Livingston Formation consists of fine to coarse tuffs, lapilli-tuffs, tuff-breccias and breccias, and some intercalated tuffaceous sandstones. (Note: It might be preferable to use the term agglomerate (and tuff-agglomerate) for many of these rocks, but the definition given by Wentworth and Williams [3, p.45] restricts the use of agglomerate to "contemporaneous pyroclastic rocks ... usually localized within volcanic vents ... or at a short distance therefrom ..." The author suggests dropping the above part of the definition and keeping only "pyroclastic rocks containing a predominance of rounded or subangular fragments greater than 32 mm in diameter, lying in an ash or tuff matrix. The form of the fragments is in no way determined by the action of running water, as in volcanic conglomerates, but is a primary feature determined during the actual eruption." Agglomerate could then be applied to coarse deposits of rounded or subangular material, formed, for instance, by mudflows and deposited perhaps relatively far from a vent. The mudflow-deposits might thus still be called agglomerates, whether they were formed directly in connection with eruptions and so in a sense are "primary" and consist of essential fragments, or were formed somewhat later and are "secondary" and consist of either essential or accessory fragments. However, as the deposits described in this paper seem to be similar to those described by Anderson [2], the author is following his usage of the terms tuff-breccia and breccia.) As viewed from a distance, most of it is well-bedded. Many of the beds, especially the thick breccias, extend with a rather uniform thickness for considerable distances. Some beds, however, vary in thickness from place to place, or are small local lenses.

### Mineralogy and composition

There are, in general, two types of igneous rocks present in the pyroclastic deposits. One is a pyroxene andesite containing phenocrysts of a pale-green augite and labradorite, and considerable accessory magnetite and some apatite. The second type is a hornblende andesite, of which two varieties are found; one contains fresh pale-green hornblende, the other an altered reddish-brown hornblende surrounded by a thick opaque reaction-rim. In addition, both varieties contain calcic andesine, minor amounts of biotite, orthoclase, magnetite, apatite, and, rarely, a little quartz. Devitrified glass occurs in some of the smaller lithic fragments, but no recognizable glass particles were seen in the tuffs or the matrix of the breccias.



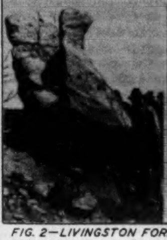


*FIG. 2—LIVINGSTON FORMATION NEAR NYE, MONTANA*

*FIG. 3—LARGE ANDESITE BLOCK IN A TUFF BRECCIA*

*FIG. 4—TYPICAL PYROXENE ANDESITE BRECCIA IN LIVINGSTON FORMATION*

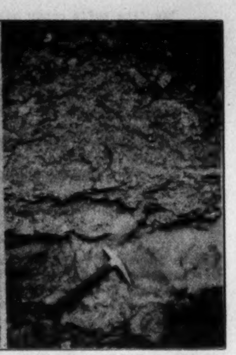


*FIG. 5A—PYROCLASTIC BED IN LIVINGSTON FORMATION, SHOWING FINE TUFF GRADING UPWARDS INTO MEDIUM TO COARSE TUFF AND LAPILLI-TUFF, WHICH IN TURN GRADES UPWARDS INTO THICK BRECCIA*

*FIG. 5B—CLOSE-UP OF LOWER PART OF VIEW SHOWN IN FIGURE 5A; FINE TUFF GRADING UPWARDS INTO COARSER CRYSTAL TUFF AND CRYSTAL-LITHIC LAPILLI-TUFF. (THE DARK SPOTS ARE THE CHLORITIC ALTERATION DESCRIBED IN TEXT)*

The pyroxene andesite breccias are by far the more abundant type. They occur both below and above the hornblende andesite breccias, and also compose most of the upper part of the section, which underlies the upland area.

In general, there is no mixing of pyroxene and hornblende andesite fragments in the same tuff-breccia or breccia-bed. For the most part, however, the fragments within each bed show marked variations in color and texture, that probably indicate derivation from different parts of the same eruption. The color differences no doubt depend mostly upon degree of oxidation (perhaps both during and after eruption) and textural differences upon rates of cooling. In a few beds the fragments are mostly of one color and texture, and superficially resemble flow-breccias where the matrix has undergone the low-grade metamorphism described below. Some tuff-breccias and breccias, however, do show a mixture of both pyroxene and hornblende andesite fragments, and, of course, the waterlaid tuffs and tuffaceous sandstones contain detritus from both types.

The exceptionally few accidental blocks found in the Formation include fragments of red shale, several porphyritic intrusive rocks, and one block resembling an altered noritic anorthosite, of the type found in the pre-Cambrian Stillwater igneous complex.

## Stratigraphy

Sections of the pyroclastic rock show considerable variation, and no definite correlation from place to place was attempted except where it was possible to trace a bed continuously. The general succession at Nye (Fig. 2) is fairly typical of the Livingston Formation. Near the base of the section is a considerable thickness of moderately resistant brown to grey tuffs and breccias, in part well-sorted. This grades upwards into yellow leaf-bearing tuffaceous sandstone, which ranges in grain-size from silt to coarse grit. This sandstone is lenticular and pinches out within a short distance. (Other sandstones occur in this part of the Livingston Formation at different stratigraphic levels, and all are lenticular; this is true also, but to a less extent, of many of the hornblende andesite beds.) Above the sandstone are several hundred feet of thin- and thick-bedded white tuffs and tuff-breccias (white cliff in Fig. 2). The upper part of this section consists of a great thickness of brown to dark-grey cliff-forming coarse and fine tuff-breccias, and breccias separated by thin bands of tuff. More of these thick tuff-breccias and breccias occur higher in the Formation.

The fine tuffs occur mostly as continuous, rather thin bands, but in places beds as much as four feet thick were found; the finest-grained varieties consist of indistinguishable material containing only a few recognizable fragments of feldspar, pyroxene, and hornblende. Medium to coarse tuffs and lapilli-tuffs are generally in somewhat thicker beds than the fine tuffs. The medium to coarse varieties are crystal tuffs consisting of angular fragments of feldspar, pyroxene, hornblende, and magnetite, and a small percentage of lithic fragments. The lapilli-tuffs are crystal-lithic tuffs, and they grade into fine tuff-breccias and breccias as the size of the lithic fragments increases. Some tuffs show such evidences of water-sorting as graded-bedding, layers of magnetite grains, and some cross-bedding.

The tuff-breccias, and especially the breccias, form the thickest beds of the Livingston Formation. The tuff-breccias consist of an extremely heterogeneous mixture of material of all sizes. The matrix is predominately crystal-lithic tuff to lapilli-tuff, and some extremely fine material; the blocks are mostly under a foot in diameter, but larger ones, five to ten feet in diameter, are not uncommon (Fig. 3). The blocks in the breccias commonly range from six to twelve inches in diameter, though in some beds they may range from four inches to two feet, and scattered blocks may be much larger. For the most part, the blocks are subangular or even fairly well-rounded (Fig. 4).

The different types of pyroclastic rock described above occur as distinct units separated by more or less definite bedding-planes. In addition, however, there is also a particular type of bed, occurring as a distinct unit, which shows a rather definite and unusual succession of changes in the size of the constituents (Figs. 5-A and 5-B). At the base of the bed is a layer, one to several inches thick, of fine tuff, grading upwards into several feet of crystal tuff. The crystal tuff changes gradually upwards into a crystal-lithic lapilli-tuff, which in turn grades into a breccia. This is the thickest part of the bed and may reach a maximum of 50 feet or more. In the fine tuff, leaf-impressions were seen at several places. The breccias are more resistant to weathering than the finer material and stand out distinctly in the cliffs (upper part of Fig. 2). Beds showing this succession of changes occur repeatedly throughout the section, and are especially well developed in the upper part.

## Metamorphism

Certain features in some of the pyroclastic beds point to a low-grade metamorphism. Some of the beds, especially in the thick pyroxene andesite breccias, have a darker grey color and are much more indurated than the less-altered beds. They have a clean fracture that breaks across rock-fragments and crystals, and some of the crystal tuffs and breccias have such a massive appearance that they might easily be mistaken in the field for flows and flow-breccias. Chlorite was found in all thin-sections of these altered beds. In some rocks chlorite replaces entirely the finer material of the matrix and fills cavities and cracks in the crystals; it may also replace the ground-mass of the lithic fragments. Two kinds of chlorite occur in some rocks; a pale-green variety which replaces the matrix, and a yellowish-green variety which fills the cavities and cracks and is more definitely fibrous. Other secondary minerals, as chalcedony, celadonite, and zeolites, were found in small amounts in the chloritized rocks.

Other beds appear to have been less intensely altered and show only spots of chloritization. Many fine-grained brown tuffs have such spots of a darker-grey color, which range in size from about one mm to five mm; the spots may be either widely scattered or so thickly clustered that several coalesce to form large dark areas somewhat harder than the surrounding tuff (Fig. 5-B). Similar spots have developed in the coarser crystal tuffs, lapilli-tuffs, and breccias; they are larger, ranging from about 5 to 20 mm in diameter. In polished hand-specimens it can be seen that the texture within the spots is not different from that outside; also, that the spots are equally well developed in both the lithic fragments and the crystal tuff-matrix. Chlorite is present in the spots, though it is less abundant than in the thoroughly indurated beds. As these hard spots resist weathering much more than the surrounding rock, they weather out and accumulate on the surface as small pebbles.

After studying the thin-sections and reviewing the field-evidence, it is concluded that both the dark indurated rocks and the spotted ones had a similar origin, and that the thoroughly indurated rocks have resulted where the spots coalesced as chloritization became more intense. The developments of this low-grade metamorphism was no doubt closely connected in some way with the formation of the individual beds. It is limited in distribution to individual beds; that is to say, a bed of breccia may be indurated or spotted, whereas adjacent beds below and above may show no such alteration, though similar in texture and composition; and, at least so far as they were followed, the degree of alteration of particular beds does not appear to change laterally.

## Conclusions

(a) The Livingston Formation as a whole is well stratified, and individual beds are continuous over a considerable area at rather uniform thicknesses. The beds were probably deposited on a relatively low-lying area of slight relief, at some distance from the volcanic center, rather than so close to the source as to be on the slopes of a volcano. There are no known sources for the material within the area studied, except possibly for a few small, discontinuous dikes.

(b) The tuffaceous sandstone-lenses and the bedded tuffs apparently are waterlaid deposits, which formed along stream-courses or in depressions. However, the coarse and often heterogeneous breccias and tuff-breccias could hardly have been deposited by running water.

The Livingston Formation appears to be similar in many respects to the Tuscan Formation of northern California, described recently by Anderson [2]. After careful analysis of all possible ways in which volcanic breccias may be formed, Anderson shows that the Tuscan breccias could not have been formed as the direct products of eruption, whether of the Vulcanian, the Peléan (nuées ardentes), or the ultra-Vulcanian type. Therefore, he limits the possibilities to mudflows, of which there are two main kinds. Hot mudflows may be produced in connection with eruptions, by eruption through a crater-lake, eruption accompanied by melting of snow and ice, or by eruption following or accompanied by heavy rains. On the other hand, cold mudflows can be produced independently of an eruption, by collapse of a dam of a crater-lake, by heavy rains falling upon unconsolidated ejecta, or by the rapid melting of snow and ice on a volcanic cone.

Following similar reasoning, the author believes that most of the breccias of the Livingston Formation were formed by mudflows. It is realized, however, that nuées ardentes might have formed some of the less continuous, but fairly thick tuff-breccias, in as much as this area probably is closer to the volcanic center than the one described by Anderson.

(c) In answer to the question of whether hot or cold mudflows formed the different beds, it is believed that the low-grade metamorphism of the beds, as described above, gives a clue to the problem. Development of the chlorite is apparently connected with the formation of the individual beds, and the suggestion is made that the thoroughly chloritized, indurated breccias were formed from hot mudflows, the spotted beds from somewhat cooler, but still heated mudflows, and the unaltered ones from cold mudflows.

(d) No satisfactory solution is offered to explain the peculiar type of bed which shows what might be called large scale "graded-bedding-in-reverse," that is, coarse material on top grading down into a crystal tuff and fine tuff; there are no apparent bedding planes within the unit, the finer-grained lower portions do not appear to have been channelled, and the whole bed seems to have been formed as a unit.

Possibly such a succession can be explained as controlled in some way by the "internal dynamics" of mudflows, or possibly the sequence of events at an eruption may have had a direct control upon the mudflow-deposits; that is, if mud were flowing rather continuously during some phase of an eruption, fine material might have been available first, and as the eruption became more active coarser material was available to the mudflow.

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U. S. Geological Survey,
Washington, D. C.

# VOLCANIC SEQUENCE IN THE MARYSVALE REGION IN SOUTHWEST-CENTRAL UTAH

Eugene Callaghan

(Published with the approval of the Director, U. S. Geological Survey)

## Introduction

As a consequence of the detailed investigation of the alunite and other mineral deposits of the Marysvale Region in southwest-central Utah, opportunity was afforded to map and study the succession of volcanic rocks that underlie most of this area. The Marysvale Region is part of a large area of volcanic rocks, which occupies much of the High Plateaus of Utah (Fig. 1). It is believed that the Marysvale Region covers sufficient area to furnish an adequate sample of this volcanic area, and, though horizontal variations are known to occur, the study may serve as a guide as to what may be expected in other parts of the area. The chemical analyses are the most completely representative of any ever taken in this part of Utah, and they furnish a basis of comparison within the High Plateaus and with other areas in Utah.

The rocks in the Marysvale Region range from basalt to rhyolite, with latite and rhyolite as the dominant groups. Volcanic breccias and tuffs make up the greater volume of material. Three groups are distinguished: First, an earlier Tertiary group of latitic breccias, tuffs, and flows; second, a later Tertiary group of rhyolites, quartz latites, latites, and tuffs; and, third,

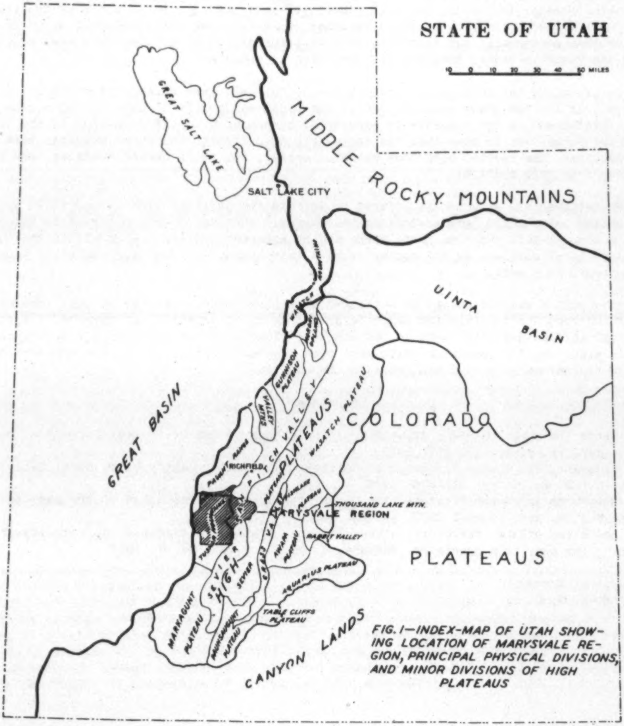
STATE OF UTAH
10 0 10 20 30 40 50 MILES
GREAT SALT LAKE
SALT LAKE CITY
MIDDLE ROCKY MOUNTAINS
UINTA BASIN
GREAT BASIN
COLORADO
PLATEAUS
CANYON LANDS
HIGH PLATEAUS
WASATCH MOUNTAINS
GUNNISON PLATEAU
VALLEY MTNS
SAN PITCH VALLEY
WASATCH PLATEAU
PAVANT RANGE
RICHFIELD
PLATEAU
FISHLAKE PLATEAU
THOUSAND LAKE MTN.
MARYSVALE REGION
RABBIT VALLEY
AWAPA PLATEAU
GRASS VALLEY
SEVIER
SEVIER
AQUARIUS PLATEAU
TABLE CLIFFS PLATEAU
MARKAGUNT PLATEAU
PAUNSAUGUNT PLATEAU

FIG. 1—INDEX-MAP OF UTAH SHOWING LOCATION OF MARYSVALE REGION, PRINCIPAL PHYSICAL DIVISIONS, AND MINOR DIVISIONS OF HIGH PLATEAUS

scattered thin basalt-flows, most of which are associated with the late Pliocene or early Pleistocene Sevier River formation. The position in the sequence of a group of basaltic breccias and flows in the southern part of the area is uncertain. It is the purpose of this paper to point out the stratigraphic relations of each of the units, to describe some of their general features, as well as some of the more pertinent petrographic features, particularly of the analyzed specimens. Suggested interpretations, based on the descriptions and the analyses, are made.

## General geology

As shown in Figure 1, the Marysvale Region lies within the High Plateaus of Utah, a part of the Colorado Plateaus, but faces the Great Basin on the west. It is part of a region of long strips of upland and rugged mountains that break sharply into longitudinal valleys, a region long ago made known through Dutton's [see 1 under "References" at end of paper] classic descrip-

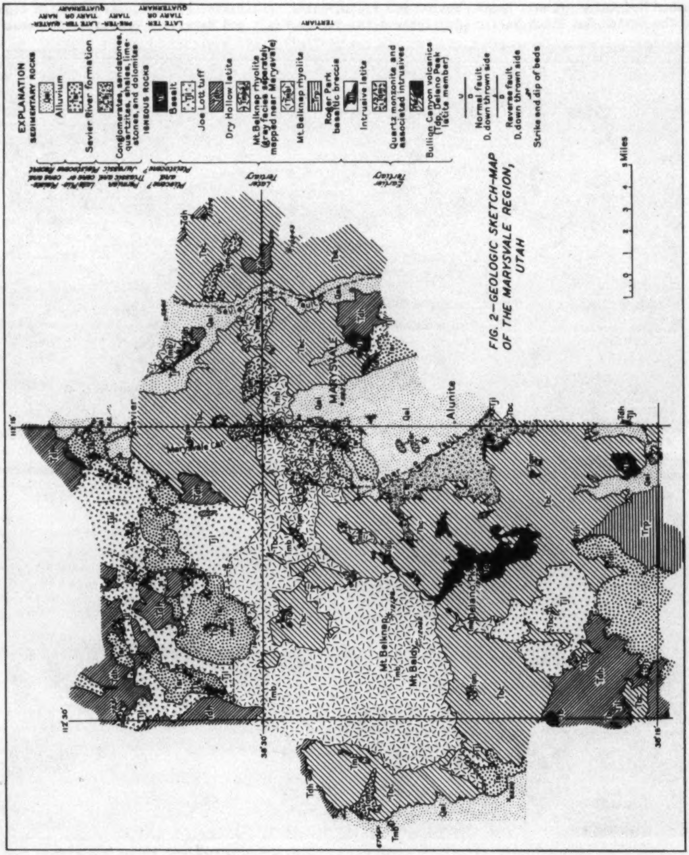
EXPLANATION
SEDIMENTARY ROCKS
Qal Alluvium
QTs Sevier River formation
Conglomerates, sandstones, quartzites, shales, limestones, and dolomites
IGNEOUS ROCKS
Tb Basalt
Tjl Joe Lott tuff
Tdh Dry Hollow latite
Mt. Belknap rhyolite (gray facies separately mapped near Marysvale)
Tmb Mt. Belknap rhyolite
Tr Roger Park basaltic breccia
Ti Intrusive latite
Tqm Quartz monzonite and associated intrusives
Tbc Bullion Canyon volcanics (Tdp, Delano Peak latite member)
Normal fault, D, down thrown side
Reverse fault, D, down thrown side
Strike and dip of beds
QUATERNARY
LATE TERTIARY OR QUATERNARY
PRE-TERTIARY
LATE TERTIARY OR QUATERNARY
TERTIARY
Late Pleistocene and Recent
Late Pliocene or Pleistocene
Permian, Triassic and Jurassic
Pliocene? and Pleistocene?
Later Tertiary
Earlier Tertiary
0 1 2 3 4 5 Miles
112°15'
112°30'
38°30'
38°15'
Marysvale
Sevier
Alunite
Marysvale Cn.
Sevier fault
Mt. Belknap
Mt. Baldy
Delano Pk.

FIG. 2—GEOLOGIC SKETCH-MAP OF THE MARYSVALE REGION, UTAH

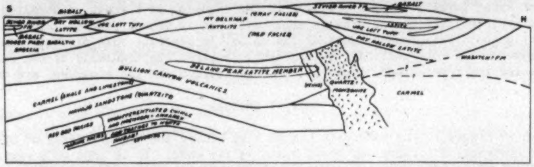
S
N
BASALT
SEVIER RIVER FM
DRY HOLLOW LATITE
JOE LOTT TUFF
BASALT
ROGER PARK BASALTIC BRECCIA
MT BELKNAP RHYOLITE
(GRAY FACIES)
(RED FACIES)
SEVIER RIVER FM
BASALT
LATITE
JOE LOTT TUFF
DRY HOLLOW LATITE
WASATCH? FM
DELANO PEAK LATITE MEMBER
BULLION CANYON VOLCANICS
(VEINS)
QUARTZ MONZONITE
CARMEL
CARMEL (SHALE AND LIMESTONE)
NAVAJO SANDSTONE (QUARTZITE)
UNDIFFERENTIATED CHINLE AND MOENKOPI
RED BED FACIES
KAIBAB?

FIG. 3—DIAGRAMMATIC SECTION OF FORMATIONS IN THE MARYSVALE REGION

tion. The Marysvale Region embraces parts of four minor divisions of the High Plateaus, the Tushar Mountains, Pavant Range, Sevier-San Pitch Valley, and Sevier Plateau. As shown in Figure 2, the Sevier-San Pitch Valley lies between the Tushar Fault and Marysvale Canyon on the west and

FIG. 4—VIEW OF EASTERN FRONT OF TUSHAR MOUNTAINS NEAR MARYSVALE (RIGHT MIDDLE GROUND)

FIG. 5—WESTERN FRONT OF SEVIER PLATEAU (DISTANCE IN BACKGROUND) AND MINOR MOUNTAIN BLOCKS WITHIN SEVIER-SAN PITCH VALLEY (LOOKING EAST FROM ALUNITE)

the Sevier Fault on the east. It thus includes several low mountain blocks, of which the Antelope Range, northeast of Marysvale, is the most prominent, as well as the alluvial valley-floor (middle ground, Fig. 4). Along the course of the Tushar Fault, the Tushar Mountains face the Sevier-San Pitch Valley in a very steep front (Fig. 4); the summits are 6000 feet above the valley-floor. The Sevier Plateau, which lies east of the Sevier Fault (Fig. 2), also has a steep scarp facing the valley to the west (Fig. 5). Summits in this plateau likewise rise nearly 6000 feet above the valley-floor. On the north the Tushar Mountains are separated from the Pavant Range, a dissected region of relatively less relief, by the downwarped area of the Clear Creek Basin, which lies west of Sevier (Fig. 2). Though not as steep as the eastern front, the western front of the Tushar Mountains breaks sharply into the Great Basin. All the elevated areas are deeply dissected, and the margins of the plateau-blocks are notched by profound canyons, such as are shown in Figures 2 and 4.

Various phases of the geology of the Marysvale Region have been described by Dutton [1], Butler and Gale [2], Loughlin [3], Butler [4], and Eardley and Beutner [5], and all previous work has been reviewed by Callaghan [6]. As shown in Figure 2, almost the entire region is underlain by volcanic rocks of Tertiary age. Pre-Tertiary sedimentary rocks--quartzites, dolomites, limestones, shales, sandstones, and minor conglomerates--are exposed in the steep eastern face of the Tushar Mountains (Figs. 2 and 4). Rocks of Permian, Triassic, and Jurassic age have been distinguished (Fig. 3). No Cretaceous rocks and no rocks assigned to the Wasatch formation, which are so prominent west of Richfield (Fig. 1), crop out in the Marysvale Region. Erosion remnants of the sedimentary Sevier River formation [6, pp. 100-101] overlie nearly all the volcanic rocks. This is a local formation derived from whatever rocks it happens to lie upon. It is believed to be of late Pliocene or early Pleistocene age. Alluvium of several ages occupies parts of the Sevier-San Pitch Valley and the Great Basin to the west.

The extrusive igneous rocks, whose stratigraphic relations are shown diagrammatically in Figure 3, are divided into three principal groups on the basis of profound breaks in the sequence. The earlier Tertiary group, called the Bullion Canyon volcanics, is perhaps the most wide-spread in the whole High Plateaus. Except in the Pavant Range, it occurs in all the local physical divisions. It has the greatest economic importance of all the groups in that the mineral deposits are confined to it. Largely made up of tuffs and volcanic breccias, it also contains a variety of latite-flows. Quartz monzonite and related intrusives are confined to it. An erosion interval separates the earlier Tertiary group from the later Tertiary group, for rhyolite of the later group rests directly on eroded quartz-monzonite. Rhyolite, latite, quartz latite, tuff, and possibly a group of basaltic breccias, whose complex stratigraphic relations are brought out in the following detailed descriptions and in Figure 3, compose the later Tertiary group. Thin basalt-flows, most of them closely associated with the Sevier River formation, make up the relatively minor third group.

The structure of the Region is relatively simple. The major blocks are outlined by normal faults and flexures as well as by erosion-forms. The rocks of the main mass of the Tushar Mountains dip gently to the west, but at the north end they dip into the downwarped Clear Creek Basin and to the northeast in the vicinity of Marysvale Canyon. The Antelope Range north of Marysvale is essentially an arm of the Tushar Mountains, which plunges eastward against the Sevier Fault. Later Tertiary rocks dip to the north and to the south from this eastward-trending axis, which is athwart the course of the Sevier-San Pitch Valley. The Sevier River has cut a deep trench, Marysvale Canyon, through this obstruction. The southward-dipping later Tertiary rocks are shown at the right-hand in the middle ground of Figure 5. Longitudinal blocks occupy the valley southeast of Marysvale. Most of the rocks in the Sevier Plateau dip eastward, and those in the Pavant Range within the mapped area dip to the south or southeast. Though there were doubtless earlier periods of deformation, the principal movement that has produced the present topography occurred after the deposition of the Sevier River formation; that is, after late Pliocene or early Pleistocene time. The last (Wisconsin?) glaciation has modified the summits of the Tushar Mountains, but little change has taken place in the land-surface since the last ice-age.

## Earlier Tertiary igneous rocks

Bullion Canyon volcanics and associated intrusive rocks--As might be expected from the wide extent of the earlier Tertiary group of volcanic rocks, they vary greatly from place to place in proportion of flows to pyroclastics, in the type of rock, and in the degree of alteration. Nevertheless, a glance at the map (Fig. 2) shows that these rocks are widely distributed in the Tushar Mountains, in the Sevier Plateau, and in the lower mountains such as the Antelope Range and the longitudinal blocks east of Marysvale. With them are associated all the obviously granular intrusives and all the mineral deposits. No exact measurement is possible, but the total thickness in the Marysvale Region is at least 5000 feet.

Southwest of Marysvale in the eastern part of the Tushar Mountains, three distinct parts of the Bullion Canyon volcanics can be distinguished. The lower part, about 2500 feet thick six miles southwest of Marysvale, consists chiefly of latitic and andesitic tuffs and breccias with scarcely ten per cent of flows. At the base is a thin conglomerate, which rests unconformably upon the older sedimentary formations and consists of debris from the underlying rocks exclusively. Above the conglomerate is waterlaid tuffaceous sandstone, which contains some detrital material from the older rocks. Most of the lower part, however, consists of massively bedded tuffs, crystal tuffs, and minor coarse breccias with a few latite-flows, all well exposed in Bullion Canyon (Fig. 6).

The Delano Peak latite-member of the Bullion Canyon volcanics is a lenticular mass that forms conspicuous cliffs (Fig. 6), facing to the east at the highest part of the crest of the Tushar Mountains (Fig. 2). Faulted segments are preserved on some of the ridges, which branch to the east. Though the thickness is over 800 feet in the center of the lens, no separate flows could be distinguished. However, the upper part has more the appearance of a flow-breccia. The

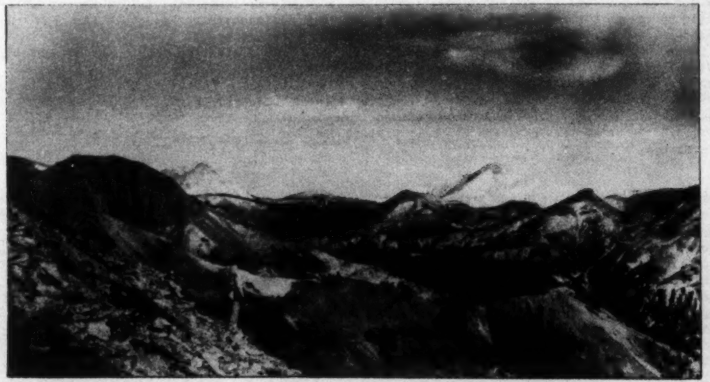

FIG. 6—GLACIATED AREA AT HEAD OF BULLION CANYON NINE MILES SOUTHWEST OF MARYSVALE, SHOWING VOLCANIC BRECCIAS AND FLOWS OF BULLION CANYON VOLCANICS (DELANO PEAK LATITE-MEMBER IN HIGH CLIFF AT LEFT AND RHYOLITE IN PEAKS IN DISTANCE)

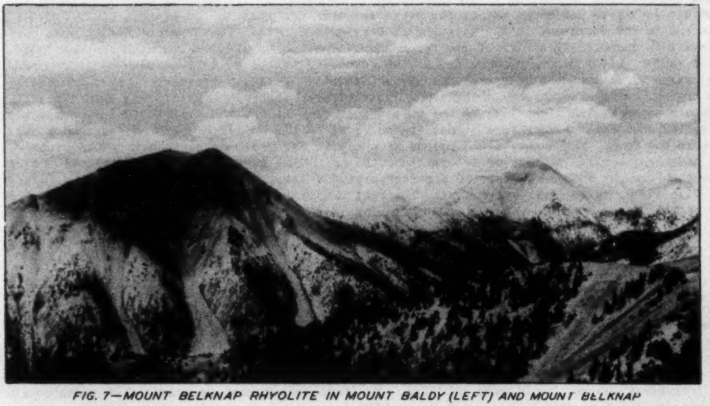

FIG. 7—MOUNT BELKNAP RHYOLITE IN MOUNT BALDY (LEFT) AND MOUNT BELKNAP

rocks in contact with it are not metamorphosed, and there is no evidence that it may be intrusive.

In the upper part of the Bullion Canyon volcanics west of Marysvale the proportion of flows to breccias is distinctly higher than in the lower part. This may exceed 50 per cent. They are mostly dark gray, some are nearly black, and most of them have a more calcic appearance than flows in the lower part. The total thickness is unknown, but is probably in excess of 2500 feet. These rocks crop out in the northern, western, and southern parts of the Tushar Mountains.

In the Sevier Plateau east of the Sevier Fault (Fig. 2), the earlier Tertiary rocks consist of a thick series of latitic breccias and thin flows at the base, a succession of latite-flows with almost no intervening volcanic breccia, and more calcic latite at the top. No exact correlation between the members in the Tushar Mountains and those in the Sevier Plateau is possible. Probably the lower breccias correspond to the lower part in the Tushar Mountains, and the remainder correspond to the upper part; the base is not exposed. The total thickness is over 5000 feet. Probably the calcic latite-flows and breccias in the Antelope Range east and north of Marysvale belong to the upper part of the Bullion Canyon volcanics.

The mineral and chemical composition of four rocks from the Bullion Canyon volcanics is given in Table 1. A fragment from a dark purplish-gray andesitic breccia (Column 4, Table 1) be-

Table 1--Analyses, norms, and modes of igneous rocks from the Marysvale Region, Utah

| Item | Specimen number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Analyses | | | | | | | | | | | | | |
| $SiO_2$ | 48.65 | 54.71 | 57.62 | 57.83 | 57.96 | 59.16 | 59.57 | 62.25 | 67.18 | 70.17 | 75.83 | 76.15 | 76.16 |
| $Al_2O_3$ | 10.40 | 11.59 | 14.54 | 13.34 | 15.71 | 16.08 | 16.92 | 15.61 | 12.00 | 11.83 | 12.36 | 12.56 | 12.64 |
| $Fe_2O_3$ | 7.45 | 3.62 | 6.55 | 7.21 | 3.38 | 3.98 | 2.85 | 5.04 | 1.44 | 0.93 | 1.05 | 0.80 | 0.88 |
| FeO | 6.05 | 4.07 | 1.09 | 0.87 | 4.11 | 1.39 | 2.08 | 0.38 | 0.14 | none | 0.29 | 0.39 | 0.14 |
| MgO | 5.55 | 6.85 | 3.20 | 1.10 | 3.16 | 2.76 | 2.05 | 1.83 | 0.43 | 0.06 | 0.02 | 0.02 | 0.23 |
| CaO | 8.10 | 6.03 | 6.08 | 5.60 | 5.11 | 3.37 | 4.41 | 4.62 | 2.65 | 0.76 | 0.04 | 0.18 | 0.04 |
| $Na_2O$ | 2.77 | 2.45 | 3.18 | 5.76 | 3.48 | 4.23 | 3.73 | 3.88 | 1.14 | 3.85 | 3.94 | 4.43 | 3.54 |
| $K_2O$ | 3.40 | 2.89 | 3.12 | 1.08 | 4.08 | 4.16 | 4.98 | 2.81 | 3.71 | 3.74 | 5.08 | 5.13 | 4.75 |
| $H_2O+$ | 1.09 | 2.88 | 1.18 | 0.95 | 1.26 | 1.98 | 1.36 | 1.34 | 7.06 | 8.72 | 0.42 | 0.40 | 0.54 |
| $H_2O-$ | 0.62 | 0.47 | 1.18 | 0.24 | 0.11 | 0.61 | 0.24 | 1.16 | 3.69 | - | 0.24 | 0.09 | 0.50 |
| $TiO_2$ | 4.75 | 2.28 | 0.81 | 0.96 | 1.05 | 0.55 | 1.34 | 0.58 | 0.20 | 0.17 | 0.24 | 0.18 | 0.15 |
| $P_2O_5$ | 0.51 | 0.42 | | 0.38 | | | 0.36 | | 0.06 | | 0.01 | none | none |
| MnO | 0.10 | 0.10 | 0.10 | 0.06 | 0.11 | 0.05 | 0.06 | 0.05 | 0.03 | | 0.12 | 0.06 | 0.06 |
| $CO_2$ | 0.86 | 1.88 | 0.86 | 4.73 | trace | 1.55 | | 0.02 | trace | | | | |
| $ZrO_2$ | 0.01 | | | 0.01 | | | | | 0.03 | | | | |
| $SO_3$ | | | | | | | | | | | | | 0.11 |
| BaO | 0.12 | | | 0.10 | | | 0.16 | | 0.01 | | 0.01 | 0.01 | 0.02 |
| $Li_2O$ | | | | | | | | | | | | | 0.003 |
| S | 0.07 | 0.06 | 0.04 | 0.07 | 0.07 | 0.04 | | 0.05 | 0.08 | | | | |
| $Cr_2O_3$ | | | 0.03 | none | 0.02 | 0.02 | | 0.02 | 0.01 | | | | |
| | 100.40 | 100.30 | 99.58 | 100.29 | 99.61 | 99.93 | 100.11 | 99.64 | 99.86 | 100.23 | 99.65 | 100.40 | 99.76 |
| Norms | | | | | | | | | | | | | |
| Q | 3.06 | 12.72 | 13.38 | 18.30 | 7.20 | 11.34 | 8.28 | 17.34 | 40.74 | 31.98 | 33.24 | 31.02 | 37.14 |
| or | 20.02 | 17.24 | 18.35 | 6.67 | 24.26 | 25.02 | 29.47 | 16.68 | 21.68 | 21.68 | 30.02 | 30.02 | 28.36 |
| ab | 23.45 | 20.96 | 27.25 | 48.73 | 29.34 | 35.63 | 31.44 | 33.01 | 9.43 | 32.49 | 33.54 | 36.68 | 29.34 |
| an | 5.84 | 11.95 | 15.85 | | 15.01 | 6.95 | 14.73 | 16.68 | 12.23 | 3.89 | 0.28 | | 0.28 |
| C | | | | 2.55 | | 2.04 | | | 1.73 | 0.10 | 0.31 | | 1.63 |
| th | | | | | | | | | | | | | 0.14 |
| wo | 10.79 | 1.39 | 3.83 | | 4.29 | | 2.20 | 2.55 | | | | 0.46 | |
| en | 13.90 | 17.10 | 8.00 | 2.80 | 7.90 | 6.90 | 5.10 | 4.60 | 1.10 | 0.20 | | | 0.60 |
| fs | | 0.53 | | | 2.90 | | | | | | | | |
| ac | | | | | | | | | | | | 0.46 | |
| mt | 5.80 | 5.34 | 1.62 | | 4.87 | 3.02 | 3.02 | | | | 0.70 | 0.93 | 0.23 |
| il | 9.12 | 4.41 | 1.52 | 1.82 | 2.13 | 1.06 | 2.58 | 0.91 | 0.15 | | 0.46 | 0.46 | 0.30 |
| hm | 3.52 | | 5.44 | 7.20 | | 1.92 | 0.80 | 5.12 | 1.44 | 0.93 | 0.64 | | 0.80 |
| ru | | | | | | | | 0.16 | 0.16 | 0.16 | | | |
| ap | 1.34 | 1.01 | | 1.01 | | | 1.01 | | 0.34 | | | | |
| pr | 0.12 | 0.12 | | 0.12 | 0.12 | | | | 0.12 | | | | |
| cc | 1.92 | 4.34 | 1.92 | 9.30 | | 3.54 | | | | | | | |

Table 1--Concluded

| Item | Specimen number | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| | | | | | | Modes | | | | | | | |
| Quartz | | x | x | x | 6 | x | x | 6 | x | | x | 26 | x |
| Orthoclase | | | | | 29 | x? | | | x | | }x | }67 | x |
| Oligoclase | | x | | x | 33 | 35 | x | 39 | | | | | |
| Andesine | x | | 22 | | | | x | | x | | | | |
| Hornblende | | x | 2 | x? | | $8^1$ | | 12 | | | | | |
| Biotite | | | | | $14^2$ | $6^1$ | | 5 | x | | x | 5 | x |
| Augite | x | x | 9 | | 11 | | x? | | | | | | |
| Olivine | x | | | | | | | | | | | | |
| Magnetite | x | x | 6 | x | 7 | 7 | x | 4 | x | | x | 2 | x |
| Apatite | | x | x | | x | x | x | x | | | | | |
| Titanite | | | | | x | | | | | | | | |
| Rutile | | | | | | | | | | | | x | |
| Tourmaline | | | | | x | | | | | | | | |
| Zircon | | | | | | | | | | | x | | |
| Cristobalite | x? | | | | | | | | | | | x? | |
| Glass | | | | | | 44 | | 34 | x | | x | | x |
| Groundmass | | | 61 | | | | | | | | | | |
| Carbonate | x | x | x | x | | x | x | | | | | | |
| Chlorite | | x | x | x | x | x | x | | | | | | |
| Iron oxide | | | | x | | x | | x | x | | | x | |
| Sericite | | x | x | x | x | | x | | | | | | |
| Epidote | | x | | | x | | | | | | | | |
| Iddingsite | x | | | | | | | | | | | | |

[1] As chlorite.

[2] Mainly as chlorite.

Analysts for specimens: 1 and 2, Charles Milton; 3, 4, 5, 7, 8, and 9, R. E. Stevens; 7, 11, and 12, J. G. Fairchild; 13, J. J. Fahey; 10, W. F. Hillebrand.

Descriptions of specimens

(1) Alkalic olivine basalt (III. 5.2.3.)--Vesicular flow surrounded by alluvium on U.S. Highway 89, 7 miles south-southwest of Alunite.

(2) Intrusive calcic latite (II. 4.3.3.)--Sill intrusive at base of volcanic sequence, center Sec. 24, T. 28 S., R. 4 W., 2 miles southwest of Alunite.

(3) Calcic latite (II. 4.3.3.)--Flow 500 feet south of summit of Delano Peak.

(4) Andesite breccia (II. 4.1.5.)--Coarse breccia 1200 feet west of Mineral Products Mine, Sec. 16, T. 28 S., R. 4 W., 4 miles west of Alunite.

(5) Quartz monzonite (II. 5.2.3.)--Intrusive stock on east side of Marysvale Canyon at mouth of Deer Creek, Sec. 29, T. 26 S., R. 4 W.

(6) Latite (II. 4.2.3.)--East slope of peak, west of L. and N. claims, Sec. 18, T. 28 S., R. 5 W., 5-1/2 miles west of Alunite.

(7) Latite (II. 5.2.3.)--Thick flow on north side of Beaver Creek west center, Sec. 25, T. 27 S., R. 5 W., 2-1/2 miles northeast of Mount Belknap.

(8) Quartz latite (II. 4.3.4.)--Thick flow in Narrows of Clear Creek Canyon, Sec. 32, T. 25 S., R. 4-1/2 W., 7 miles west of Sevier.

(9) Rhyolite tuff (I. 3.3.2.)--Joe Lott tuff, east side Mill Creek, southwest center Sec. 19, T. 26 S., R. 4-1/2 W., 8-1/2 miles southwest of Sevier.

(10) Rhyolite glass or pitchstone (I. 4.1.3.)--"Edge Gold Mountain Mining District 8 miles north of west of Marysvale." U.S.G.S. Bull. 168, p. 168, 1900. Probably in Deer Creek Canyon; no description.

(11) Banded gray rhyolite (I. 4.1.3.)--Flow near base of formation NW 1/4, Sec. 7, T. 27 S., R. 3 W., 2-1/2 miles north-northwest of Marysvale.

(12) Granular gray rhyolite (I. 4.1.3.)--Flow in upper part of Mount Belknap, Sec. 34, T. 27 S., R. 5 W.

(13) Tuffaceous red rhyolite (I. 3.1.3.)--Flow making high cliffs in Marysvale Canyon at mouth of Deer Creek, NE 1/4, Sec. 1, T. 27 S., R. 4 W., 3-1/2 miles north-northwest of Marysvale.

longing to the lower part of the Bullion Canyon volcanics was found under the microscope to be finely porphyritic, with partly altered oligoclase and chlorite aggregates indicating former hornblende or augite. The maximum size of the feldspars is about 2 mm; the groundmass crystals average about 0.03 mm. The rock is considerably altered, and contains much carbonate, chlorite, and quartz, with minor sericite. The striking feature brought out by the analysis is the relatively low content of potash. The breccias with smaller fragments, mostly less than one inch in diameter, are generally light-colored, and are probably less calcic than the analyzed specimen. The massive beds of crystal tuff closely resemble normal latite, and doubtless have a closely similar chemical composition.

The Delano Peak latite-member (Column 6, Table 1) is brownish red with abundant phenocrysts of oligoclase, hornblende, and biotite, and minor quartz and magnetite in a glassy base with fluidal structure. Many of the oligoclase phenocrysts, which may reach lengths of four mm, but average from one to two mm, are fragmented, and biotite plates are commonly bent. Much of the hornblende is surrounded by an envelope of minute grains of magnetite. The red color is due to films of red hematite, which cover or completely replace grains of magnetite. Nevertheless, there are gray streaks and splotches that are characteristic of much of the mass. The analyzed specimen is somewhat altered; hornblende and biotite are changed to chlorite, and carbonate and quartz have formed to some extent in the devitrified groundmass.

A specimen (Column 4, Table 1) from Delano Peak, believed to be typical of much of the dark flows in the upper part of the Bullion Canyon volcanics southwest of Marysvale, is medium dark gray and not conspicuously porphyritic, though andesine-phenocrysts are as much as three mm long and augite grains reach two mm in length. Phenocrysts of andesine, augite, hornblende, and magnetite are scattered through a groundmass of devitrification-products and a felted mass of plagioclase microlites. Slight alteration has produced quartz, carbonate, sericite, and chlorite. Another rock (Column 7, Table 1) from the upper part of the Bullion Canyon volcanics is purplish medium gray and conspicuously porphyritic, with some phenocrysts as much as ten mm in length. The average length of the phenocrysts is one-half to two mm, and the grain-size of the groundmass is from 0.03 to 0.05 mm. The andesine-phenocrysts are mottled and variably replaced by orthoclase. The former ferromagnesian mineral, probably augite, is now represented by chlorite and carbonate. The groundmass is a fine-grained aggregate with feldspar of low index of refraction, leucoxene (?), carbonate, minor sericite, and quartz. Magnetite and apatite are accessory.

In addition to those described, there are other varieties of flow-rocks and breccias. Though most of the breccias and tuffs are medium to light-gray, tuff and breccia near Sevier (Fig. 2) is yellowish white and resembles a part of the younger Joe Lott tuff. A nearly black flow-facies of latite at the west side of the Tushar Mountains contains large andesine phenocrysts, with inclusions of orthoclase, and chlorite pseudomorphs that strongly suggest former olivine. Carbonate has developed in the groundmass of minute plagioclase-laths as well as in the phenocrysts. A dark-gray rock at the summit of the Sevier Plateau superficially resembles basalt, but under the microscope is found to be a latite with large andesine and small augite phenocrysts in a groundmass consisting chiefly of minute (0.01-0.03 mm) feldspar of low index of refraction. Some chlorite pseudomorphs suggest former olivine. Magnetite and apatite are accessory. Much of the succession in the Sevier Plateau is composed of latite with large phenocrysts of andesine and conspicuous euhedral biotite. This rock is characteristically a medium to light purplish-gray. The groundmass, which is fine-grained, with minute crystals of orthoclase and interstitial quartz, is strikingly susceptible to recrystallization through contact metamorphism.

Intrusive bodies mostly occur along an axis trending earth-northeast just north of Marysvale (Fig. 2). They are chiefly small stocks; the largest is scarcely two miles wide. Some small dikes and plugs lie outside of this axial direction, but all are confined to the Bullion Canyon volcanics. The Mount Belknap rhyolite of the later Tertiary group overlies an eroded surface on the intrusive quartz-monzonite north of Marysvale, as is shown diagrammatically in Figure 3. Perhaps as a consequence of the small size of the intrusive bodies, the grain-size and appearance change abruptly from place to place within the same mass and between different bodies. However, under the microscope the mineralogy is found to be very similar throughout.

The medium-gray quartz-monzonite (Column 5, Table 1) from the intrusive at the south end of Marysvale Canyon (Fig. 2) is the most nearly equigranular and granitoid in appearance of all those investigated. The grain-size is mostly from one to four mm for the major minerals. The plagioclase tends to be in large elongate grains, but the abundant orthoclase and less plentiful augite and biotite are nearly equant. The rock consists of calcic oligoclase, orthoclase, quartz, augite, and biotite, accessory magnetite, apatite, and titanite, and later tourmaline, epidote, chlorite, and sericite. Dusty orthoclase tends to be interstitial to the plagioclase, but it also invades and replaces it. Myrmekitic intergrowths of quartz and orthoclase are common. Though some of the augite is completely changed to chlorite, much of it is unaltered. Some of the biotite seems to be a late mineral, which formed rims at the contacts of magnetite and augite. Though the rock has less than ten per cent of quartz in either the norm or the mode, it is closer in composition to quartz-monzonite than to monzonite. A higher proportion of orthoclase to plagioclase appears in the mode than in the norm--probably some of the soda is included in the orthoclase.

In a small intrusive in a window of Bullion Canyon volcanics west of the intrusive in Marysvale Canyon, the rock is comparatively finer-grained and darker-colored than the analyzed material. Titanite and tourmaline are absent in this and all specimens other than the one analyzed. In the next group of very small intrusives to the west, one is black and not conspicuously porphyritic. It has very minor interstitial quartz, and has greater difference in size of phenocrysts and groundmass than the analyzed rock. Though it contains considerable plagioclase in the groundmass, there is replacement by orthoclase. The dark color is due chiefly to finely disseminated magnetite. This rock could doubtless be properly classified as monzonite. Minor intrusives are mostly fine-grained, but have the same mineral content as the coarser-grained bodies.

The contact-effects of the larger intrusive bodies, though variable, are characteristic. Latites in the contact-zone are mostly turned to a pink color, though in a few places they become black or green. They retain their plagioclase-phenocrysts, and in many places biotite phenocrysts are preserved, but the groundmass recrystallizes and becomes obviously granular, though very fine-grained. In the pink rock, orthoclase and minor quartz are introduced so that the groundmass becomes an aggregate of orthoclase and interstitial quartz. The degree of metamorphism is indicated by the size of grain. Though the plagioclase phenocrysts tend to persist, they are commonly partly replaced by orthoclase. Magnetite tends also to be introduced; in a number of places its abundance accounts for the black color. In one place north of Marysvale, sufficient magnetite was introduced to form an ore-body, which has been mined. Commonly a light-colored biotite has been introduced with the magnetite, so that the contact-aggregate is essentially orthoclase, magnetite, and light-brown biotite. In a few places epidote is sufficiently abundant to give a greenish cast to the rock. Chlorite is a minor constituent. In general, the outstanding feature of both the intrusive and contact-rocks is the introduction of orthoclase and replacement of earlier plagioclase.

An intrusive latite (Column 2, Table 1), which forms sills from a few feet to more than 100 feet thick southwest of Alunite (Fig. 2) deserves special mention. In intrudes the conglomerate at the base of the volcanic sequence, but was not recognized at any other horizon. The rock, which does not resemble the quartz-monzonite type of intrusive, is medium-dark gray, porphyritic, and contains small amygdules filled with quartz and carbonate. The phenocrysts, which are augite and hornblende rather than plagioclase, are mostly 0.3 to one mm long, though some are as much as five mm long. The grain-size of the groundmass is between 0.03 and 0.4 mm, but averages about 0.1 mm. Oligoclase and minor interstitial quartz compose most of the groundmass. Both phenocrysts and groundmass are, to a moderate extent, replaced by carbonate, epidote, chlorite, quartz, and a little sericite. Though superficially the rock has a diabasic appearance, the analysis shows that it belongs to the latite group. Its contact-effects on adjacent rocks are negligible.

Dikes of rhyolite porphyry, which has large phenocrysts of orthoclase, quartz, and minor plagioclase in a devitrified groundmass, intrude the Bullion Canyon volcanics, six miles southwest of Marysvale. As they are mineralized by quartz-veins older than the later Tertiary rocks, they must belong to the earlier Tertiary group rather than occurring as feeders for later Tertiary rhyolites.

The earlier Tertiary rocks are commonly much more altered than those in later groups, and this feature may be used with caution in distinguishing the two groups. The most wide-spread alteration has involved the formation of carbonate, chlorite, sericite, and minor quartz. These minerals are most abundant near some of the veins where they are often joined by disseminated pyrite. Nevertheless, the same minerals are observed in areas remote from veins.

Another type of alteration, apparently later and mutually exclusive to the type described above, is concerned with the formation of alunite and quartz, with or without associated pyrite, at the expense of pyrogenic minerals. This alteration is much more restricted in extent, though it covers small areas in the Tushar Mountains and large areas in the Antelope Range and small areas in the Sevier Plateau. Veins of alunite and some of the disseminated material were mined for potash during and immediately following the World War.

### Later Tertiary volcanic rocks

Roger Park basaltic breccia--The position of the Roger Park basaltic breccia in the volcanic sequence of the Marysvale Region is not entirely clear. The formation was recognized in a small area in the southern part of the Region, where it enters as a wedge from the south. Though it is doubtless thicker and more extensive to the south, its maximum thickness within the mapped area may be as much as 2000 feet. The Roger Park basaltic breccia is overlain by latite, grouped with the Dry Hollow latite, and is underlain by latites and breccias of the Bullion Canyon volcanics. No sharp line could be drawn between the dark calcic latites of the underlying formation and the more basaltic-appearing rocks. Indeed, this formation may be a facies of the Bullion Canyon volcanics, but further investigation must precede any definite conclusion.

The flows near the top of the formation are dark gray, and have distinctly basaltic appearance. The breccias are various shades of gray or red, and the fragments are commonly vesicular. Thin sections from fragments showed that the rock is porphyritic with phenocrysts of labradorite and pyroxene (pigeonite) as much as five mm long in a groundmass of the same minerals, mostly between 0.02 and 0.1 mm long, interstitial brown glass, and abundant magnetite-grains. No trace of orthoclase could be detected, and olivine is conspicuously absent. Toward the base, the rocks more nearly resemble the dark calcic latites.

Mount Belknap rhyolite--In the area northwest of Marysvale two distinct facies of the Mount Belknap rhyolite are readily recognized, and were separately mapped. In the western part of the Tushar Mountains, the two facies also can be recognized, but, as their contact is much less distinct, the gray facies is not distinguished on the map. These rocks characteristically break up into thin plates and scales on exposed surfaces that cover gentle slopes or form long talus cones and sheets on steeper slopes, as shown in Figure 7. Nevertheless, these rocks compose the crest of the Tushar Mountains near the northern end as well as the picturesque yellowish-white peaks, Mount Baldy and Mount Belknap (Fig. 7). The entire mass of the rhyolite forms a lenticular body in the Tushar Mountains, and in conformity with the regional structure dips to the west on the west side, to the north on the north side, and to the east on the east side. Though its base is at an altitude of over 11,000 feet in the center of the mountains, it reaches the valley-floor on either side. Each facies now has a maximum thickness of about 2000 feet, but the total original thickness in the center of the lens was doubtless in excess of 4000 feet prior to erosion.

The two facies are not equally distributed; the gray facies extends farther to the west, to the south, and to the east than the red tuffaceous facies, but the red facies extends farther to the north, where it is directly overlain by latite-flows and the Joe Lott tuff. In some places the red facies rests directly on various older rocks, including the quartz-monzonite, but in most places there is intervening bedded tuff that may be 300 feet thick. Commonly the basal portion of the red facies is marked by a black to greenish black pitchstone (Column 10, Table 1). Lenticular masses of bedded tuffs and breccias are irregularly distributed through the red facies, and coarse breccias occur in the gray facies in the western part of the Tushar Mountains. North of Marysvale the two facies are separated by tuff. The gray facies commonly has a glassy base in which occur spherulites, several inches to more than a foot in diameter.

Though the various facies of the Mount Belknap rhyolite differ strikingly in appearance, their composition is remarkably similar. A photomicrograph of typical tuffaceous red rhyolite (Column 13, Table 1) is shown in Figure 8. The mass of the rock is reddish brown to salmon colored, and though not glassy, is obviously not granular. The fragments, commonly five to ten mm in diameter, are either light or dark gray, and clearly belong to the rhyolite; foreign fragments, except near the margins of the mass are rare. In the analyzed specimen both the fragments and the mass of the rock are devitrification-aggregates. Orthoclase phenocrysts, 0.2 to 0.8 mm long, and rare quartz phenocrysts stand out in a mass of minute feldspars with some biotite flakes (Fig. 8). Magnetite occurs in the fragments, but very little appears in the groundmass. The red color is due to minute flecks of hematite. Minute sperulites occur in groups, and crystallized streaks and lenses contain orthoclase. Some cavities are lines with orthoclase and quartz-grains. The tuffaceous character of the rock naturally suggested that this might be a welded tuff, but clear evidence is lacking. A few samples have a collapsed-bubble structure that suggests welded tuff, but the inference is that the bulk of the material is a flow-breccia. A very few flows of restricted extent are purplish porphyritic rhyolite with abundant quartz and orthoclase and minor plagioclase-phenocrysts in a glassy or only slightly devitrified groundmass.

The typical gray rhyolite (Column 11, Table 1) north of Marysvale is represented by Figure 9. The striking feature is the prominent contorted flow-banding; the darker bands include material that is only slightly devitrified, and the lighter bands are more obviously crystalline. Thin lenses parallel to the flowage-lamination are filled with small quartz and orthoclase crystals, and larger cavities are lined with visible quartz-crystals, some of them amethystine. As a whole the rock is light gray, has no phenocrysts, and has thin lenses and bands of obviously crystalline quartz and orthoclase alternating with devitrified material, which shows, under the

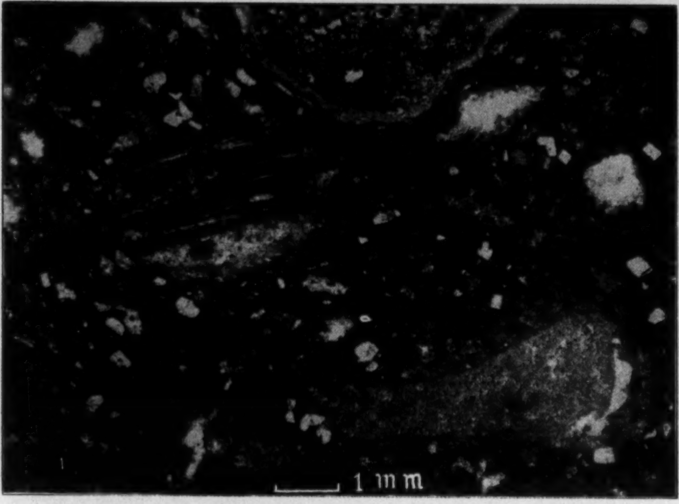

*FIG. 8—PHOTOMICROGRAPH OF TUFFACEOUS RED FACIES OF MOUNT BELKNAP RHYOLITE, SHOWING FRAGMENTS AND PHENOCRYSTS*

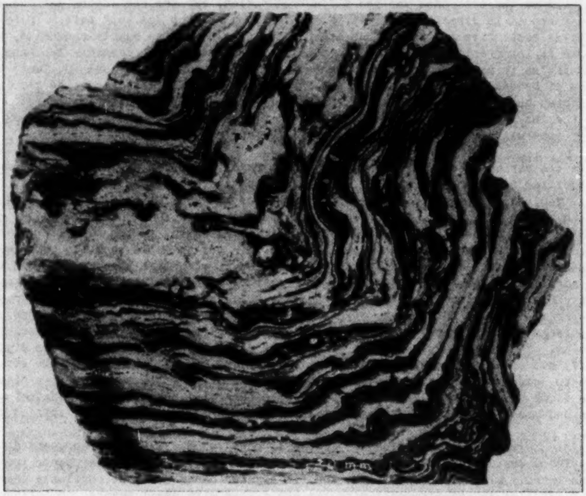

*FIG. 9—TYPICAL FLOW BANDING IN GRAY FACIES OF MOUNT BELKNAP RHYOLITE*

microscope, a pronounced orientation. Crystallization of this material must have been affected by pressure at the close of movement, whereas the unoriented quartz and orthoclase, most of which is between 0.01 and 0.07 mm long, formed after movement ceased. Minute pleochroic blebs are believed to be biotite, and one grain of zircon was seen.

Much of the banded or laminated gray rhyolite occurs on the western slope of the Tushar Mountains, but the most interesting variety, which is wide-spread and includes the upper part of Mount Belknap (Fig. 7), is a light gray to almost white rock, which resembles a very fine-grained quartzite. The rock (Column 12, Table 1) is essentially a holocrystalline, non-porphyritic, equigranular aggregate of quartz and feldspar, with very minor amounts of biotite, magnetite, red iron-oxide, and cristobalite (?). The grain-size of most of the quartz is 0.03 to 0.05 mm, and that of the feldspar is about 0.05 mm. The feldspar is all the same, a microcline microperthite. Under the microscope the feldspars show a herringbone unmixing structure, and under high magnification this structure is revealed as rows of plates of probable albite in orthoclase. No special conditions for the formation of this rock could be ascertained in the field. Though a very hazy broad flow-banding can be seen in some of the material, no data on the thickness or extent of individual flows were obtained.

Some outlying flows, one immediately west of the Sevier Fault northeast of Marysvale, and another at the west base of the Tushar Mountains (Fig. 2), differ in being distinctly porphyritic, with phenocrysts of quartz and feldspar in a devitrified base. As these flows have similar relations to the underlying rocks and doubtless differ little in composition, they are classed with the Mount Belknap rhyolite.

The Mount Belknap rhyolite contains no mineral deposits, nor is it intruded by granular rocks. However, a wide-spread alteration has bleached whole square miles of the red tuffaceous facies. This alteration has produced little change beyond the introduction of pyrite, decrease in soda, increase in potash, decrease in iron oxide, and formation of quartz and sericite. The increase in potash suggests that there has been a change in the orthoclase-content. In general, the alteration, which was probably of the hot-spring type, has only slightly modified the rhyolite in composition, though it has changed its appearance.

Dry Hollow latite--The later Tertiary latite and quartz-latite are widely distributed as erosion-remnants in all the physical divisions of the Marysvale Region (Fig. 2). Individual flows are more than 200 feet thick in many places, and the aggregate thickness is probably about 1000 feet. The latite rests upon the earlier Tertiary volcanic rocks and upon the Mount Belknap rhyolite. It is interbedded with the Joe Lott Tuff, and many flows are underlain by the tuff. It is overlain by younger rocks, including the Sevier River formation and basalt flows (Fig. 3).

A specimen (Column 8, Table 1) from a thick flow in the canyon of Clear Creek west of Sevier is brownish red and abundantly porphyritic. Dark-red spots contain few phenocrysts, and gray spots are made up almost entirely of phenocrysts. All the recognizable minerals, oligoclase, quartz, hornblende, biotite, magnetite, and apatite, occur as phenocrysts that reach a maximum length of about three mm. The groundmass contains minute grains, but is mostly fluidal light-brown glass. Coatings of red iron-oxide on the magnetite and disseminated minute red hematite-grains account for the red color. Quartz is embayed, and hornblende is partly changed to aggregates of magnetite at the margins of the crystals. The rock is unaltered, but resembles closely facies of the Delano Peak latite member of the Bullion Canyon volcanics.

Other flows of the Dry Hollow latite may differ in being gray instead of red, in having a lower proportion of phenocrysts, in having no visible quartz, or, as in the latite in the Sevier Plateau, in having large orthoclase phenocrysts. One flow has multitudes of small cavities partly or wholly filled with fibrous zeolite. Some flows closely resemble latite in the Bullion Canyon volcanics, but they are generally much less altered, and their associations serve to distinguish them from the older rocks.

Joe Lott tuff--Several discrete areas of conspicuous white to light-yellow or brownish tuff are grouped as the Joe Lott tuff, named for a creek in the northern part of the area. The largest exposures are in the basin of Clear Creek west of Sevier, and in the Beaver River Basin southwest of Delano Peak. Smaller outcrop areas occur in the Sevier-San Pitch Valley, both north and south of Marysvale. The thickness of the various outcrops of tuff is highly variable, but in the Clear Creek Basin the aggregate thickness is in excess of 1000 feet. The lower part of the tuff in Clear Creek Basin is in massive beds, in places between 50 and 100 feet thick, which along Clear Creek have columnar structure. These beds show no lamination, but thin pinkish interbeds are commonly laminated. The upper part, exposed in the northwestern part of the Region, is interbedded with abundantly porphyritic latite and quartz-latite flows of the Dry Hollow latite, and is largely composed of latite detritus. It has a pink or brownish cast, as compared with the white or light-gray cast of the lower rhyolite tuff.

Though the Joe Lott tuff rests on Bullion Canyon volcanics in a few places, and upon the Mount Belknap rhyolite, most of it rests on latite-flows belonging to the Dry Hollow latite, as

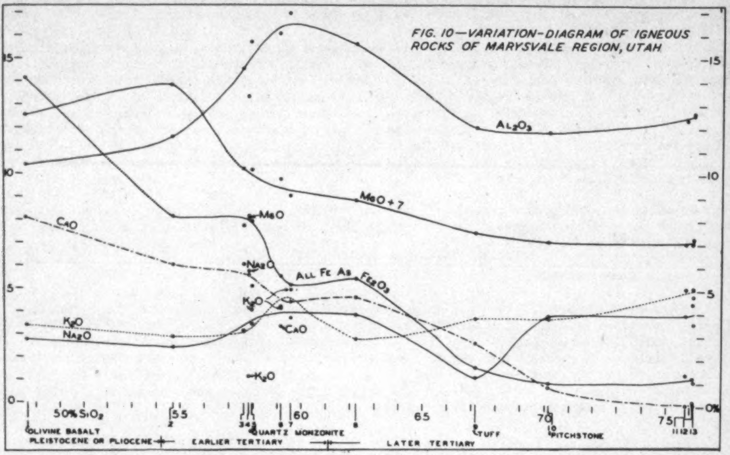

FIG. 10—VARIATION-DIAGRAM OF IGNEOUS ROCKS OF MARYSVALE REGION, UTAH

is shown in the diagrammatic section (Fig. 3). Thin tongues of the red facies of the Mount Belknap rhyolite occur in the tuff at the south side of Clear Creek Basin, but most of it is interbedded with flows of the Dry Hollow latite.

Rhyolite tuff (Column 9, Table 1) from the lower part of the Joe Lott tuff is white, ashy, and consists of white-ash fragments, mostly ten mm in diameter, and scattered fragments of dark porphyritic latite as much as 15 mm in diameter, which were doubtless derived from the Bullion Canyon volcanics, in an ashy matrix. Crystal fragments of orthoclase, biotite, and rare quartz are scattered through the glassy material. The analysis shows a higher proportion of potash to soda in the tuff than in the rhyolite. However, many fragments of the gray-banded rhyolite occur in the tuff near the rhyolite-contact.

Light-brownish crystal tuff from the upper portion is composed of the same material as the associated latite, so that even under the microscope it is scarcely distinguishable from the latite-flows.

Basalt--Flows of olivine basalt, most of them less than 50 feet thick, occur at a number of places throughout the Region. In the Clear Creek Basin southwest of Sevier and in the Beaver River Basin at the south end of the area, the basalt-flows are associated with the Sevier River formation. Elsewhere they lie upon the Bullion Canyon volcanics, the Dry Hollow latite, or the Joe Lott tuff.

A specimen (Column 1, Table 1) from an isolated outcrop in the Sevier-San Pitch Valley is an exceedingly fine-grained black vesicular rock with small phenocrysts of olivine, mostly 0.2 to 0.7 mm long, in a groundmass of andesine laths, blebs of augite, and granules of magnetite. Most of the grains in the groundmass are 0.01 to 0.04 mm long. The olivine crystals, both large and small, are stained red, and many are completely changed to iddingsite. Some isotropic grains in the groundmass are regarded as cristobalite. Other basalt-flows contain labradorite as well as olivine phenocrysts. There is little visible indication of the relatively high content of alkalies brought out in the analysis.

## Interpretation

A study of the chemical analyses given in Table 1 and the variation-diagram (Fig. 10) together with the petrographic descriptions and field-relationships lead to certain generalizations concerning the igneous rocks of the Marysvale Region. First, in a chemical sense the entire group is saturated with respect to silica in the norm. No feldspathoid minerals were recognized, and though olivine occurs in the mode of the basalt, it is absent in the norm. Second, perhaps the most characteristic feature of these rocks is the essential equality of the alkalies throughout the group. This is especially well illustrated by the end-members of the group, the basalt and the rhyolite. In the basalt the total of alkalies is high, 6.17 per cent, and only three per cent less than the total alkalies in the rhyolites. This feature is significant in that it demonstrates the alkaline habit of this group of extrusive and intrusive rocks even more conclusively than do the intermediate rocks. Third, the rocks of the Marysvale Region are comparatively low in lime. Plagioclase is commonly of the soda-lime variety, even in the more mafic specimens. Augite starts to displace biotite at a point on the diagram (Fig. 10) between 59 and 60 per cent. The three rhyolites are particularly interesting in that though they are dissimilar in structure and apparent crystallinity, their composition is almost exactly the same. The quartz-monzonite resembles in its chemical habit the typical intrusives of the western half of Utah, though it is less siliceous than most of the analyzed intrusive rocks. The almost universal habit in the Region for the orthoclase to develop at the expense of plagioclase should be emphasized.

These features of the intrusive and extrusive rocks suggest a relationship or consanguinity of all of them, a strong indication that, though widely spaced in time, they are differentiates of a parent monzonitic magma. Gilluly [7, p. 67] has already suggested a like explanation of the monzonites and latites of the Stockton-Fairfield Area. An interesting corollary of this conclusion is that the basalt is a differentiate of the monzonitic magma, rather than a representative of the basaltic substratum. In chemical composition the basalt differs from Daly's [8, p. 17] average basalt or average plateau-basalt in the markedly high percentage of potash and low content of alumina. This compositional feature seems to tie the basalt to the monzonite-latite group of rocks.

The striking similarity of the intermediate group of intrusive and extrusive rocks throughout the western half of Utah has been brought out clearly by Gilluly. He [7, p. 68] concluded that "this wide-spread similarity in the chemistry of the igneous rocks of western Utah must reflect a regional magmatic character." The evidence of the Marysvale Region even more effectively supports this conclusion. Western Utah is evidently a distinct petrographic region, part, perhaps, of a larger "petrographic province." Any conclusion as to the cause of the distinction between this Region and contiguous regions involves the whole problem of regional magmatic activity and differentiation, a problem too large to be treated adequately here.

Nevertheless, it may be well to review the concept of petrographic provinces as applied to this Region, and to compare the western Utah area with areas to the west and east. Harker [9, pp. 88-109] reviewed the concept of petrographic provinces originally advocated by Judd [10] and the contribution that Iddings had made in pointing out the alkalic nature of the rocks along the east side of the Rocky Mountains and the sub-alkalic nature of the rocks of the Great Basin and the Pacific Coast. The eastern group is included in the "Atlantic branch" of Harker, and the western group is included in the "Pacific branch." Iddings [11, p. 480] pointed out the differences between the Sierra Nevada and Cascade rocks on the one hand and those to the east, and stated that the rocks of the Great Basin are more like those of Colorado than those of the Sierra Nevada. He suggested the existence of ill-defined zones that followed the major physiographic divisions, but called attention to the variations and complexities within these zones. Washington [12, p. 380] regarded this area as part of a complex comagmatic region "with rather high silica, soda, and lime, little potash and moderate iron and magnesia." Buddington and Callaghan [13, pp. 439-442] showed by means of a variation-diagram the marked difference between the intrusive rocks of the Cascade Mountains in Oregon and those of western Utah.

A glance at the geologic map of the United States will show that the volcanic region of southwest-central Utah is essentially continuous with that of southwestern Utah, which extends westward into Nevada. Few analyses are available for this large area. Analyses from the Iron Springs Region in southwestern Utah show a high proportion of potash, and F. G. Wells [personal communication] has found that basalt in southwestern Utah has equivalent alkalies. Out on what might be considered the outer margin of the volcanic region, in the Delamar District in Nevada, the rhyolite is of the usual high-potash, low-soda type, though the intrusive rock contains equivalent soda and potash in the unmodified facies. At Gold Hill, Utah, near the Nevada boundary, Nolan [14, pp. 49-53] found that the rhyolite was potassic, though the intermediate rocks were latites, and the basalt has equivalent soda and potash. Consequently, it may be assumed that somewhere within the Great Basin there is a transitional zone between the characteristic andesites and granodiorites of the Pacific branch or province and the typical quartz-monzonites and latites of the western part of Utah. East of the High Plateaus, the intrusives that penetrate the sedimentary rocks of the Colorado Plateau are distinctly different in that they are characterized by a preponderance of soda. In fact, feldspathoids are commonly found in these rocks.

Therefore, southeastern Utah represents another minor but contiguous petrographic region. In general, the rocks of the Marysvale Region are typical of a petrographic sub-province whose boundaries are as yet undetermined.

## Conclusions

The igneous rocks of the Marysvale Region are believed to be representative of an area of volcanic rocks that occupies the central part of the High Plateaus of Utah. The aggregate thickness of the flows and pyroclastics is over 10,000 feet. They are divided into three groups on the basis of profound breaks in the sequence, and they rest upon pre-Tertiary rocks within the mapped area. Outside of the Marysvale Region, they rest upon what is regarded as an Eocene formation, and all but the last group, the basalts, are overlain by the late Pliocene or early Pleistocene Sevier River formation. The earlier Tertiary group consists of volcanic breccia, tuffs, and latite-flows, which tend to be less siliceous and more calcic than the latites, quartz-latites, rhyolites, and tuffs of the later Tertiary group. The intrusive quartz-monzonite and related rocks are confined to the earlier Tertiary group. The third and final group consists of alkalic olivine-basalt flows.

Chemical analyses bring out the most significant feature, the essential equivalence of the alkalies throughout the group from basalt to rhyolite. Petrographically, this chemical condition is suggested by the tendency of orthoclase to develop at the expense of plagioclase. The persistence of the equivalence of the alkalies suggests that the entire group is related, and that they have a common origin through differentiation from a parent monzonitic magma. The rocks of the Marysvale Region are regarded as typical of a petrographic region that includes most of western Utah.

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## MINUTES OF THE GENERAL ASSEMBLY, TWENTIETH ANNUAL MEETING (1939)

### BUSINESS SESSION

The business session of the general assembly of the American Geophysical Union was held Friday, April 28, 1938, in the Library of the National Academy - Research Council Building, Washington, D. C. The session was called to order at 12:05 p.m. by the President, R. M. Field, there being 41 members present [see Appendix A].

The minutes of the nineteenth annual meeting on April 29, 1938, were approved as published in the Transactions of that meeting.

The General Secretary presented an abstract of his report for the past year [see Appendix B]; this report was accepted and ordered filed.

The President reported informally, expressing his deep interest in the accomplishments of the Union during the past year and particularly of its special committees in their arduous tasks.

### Reports of standing committees

The General Secretary reported informally for the Membership Committee, stating that the Union now has a total membership of 1124, a gain of 117 in the past year.

Chairman H. D. Harradon of the Committee on Statutes and By-Laws stated that no changes had been made in the Statutes and By-Laws during the past year and that no matters of importance had come before the Committee.

The General Secretary read the report of the Budget Committee indicating receipts and disbursements for the fiscal year beginning July 1, 1939, totaling $6,600. This report was accepted and approved.

Chairman G. W. Musgrave of the Committee on Meetings stated his Committee hopes to prepare a set of suggestions for the incoming Committee resulting from the experience gained in connection with the arrangements made for the twentieth annual meeting.

Chairman J. A. Fleming of the Editorial and Publication Committee stated that beginning with 1939 the Committee has followed the suggestions approved by the Executive Committee and by the Union at the last annual meeting to have the Transactions spread out over the whole year. Part I, the master-copy for which is now being prepared, will include the papers presented at the two regional meetings of the Section of Hydrology at Los Angeles, California, and at Spokane, Washington, held in December, 1939; part II will include papers prepared for a "Symposium on floods," which is one of the topics to be presented by the Commission of Potamology of the International Association of Scientific Hydrology at the Washington Assembly of the International Union of Geodesy and Geophysics to be held in September, 1939; parts III and IV will contain the proceedings of the twentieth annual meetings of the Union and of its sections.

### Reports of special committees

Chairman Maurice Ewing of the Special Committee on Geophysical and Geological Study of Oceanic Basins presented a brief report; it was accepted and the complete written report was ordered printed in the Transactions [see Appendix C].

Chairman H. T. Stetson of the Special Committee on Cosmic Terrestrial Relationships presented a brief report; it was accepted and the complete written report was ordered printed in the Transactions [see Appendix D].

Chairman W. T. Thom, Jr., of the Special Committee on Geophysical and Geologicay Study of Continents presented a brief report; it was accepted and the complete written report was ordered printed in the Transactions [see Appendix E].

### Seventh Triennial Assembly

Chairman N. H. Heck of the Organizing Committee for the Seventh Triennial Assembly of the International Union of Geodesy and Geophysics read a summary of activities of the various committees on arrangements [see Appendix F]; this summary was accepted and ordered filed.

## Resolutions

The Committee on Resolutions [H. F. Johnston (Chairman), R. R. Bodle, and I. R. Tannehill] then submitted through Chairman Johnston the following seven resolutions, each of which was unanimously adopted upon motion:

(1) RESOLUTION ON LONG-RANGE WEATHER FORECASTS (submitted by Section of Meteorology)

WHEREAS, Under the Bankhead-Jones Act the United States Weather Bureau has been enabled to start research projects working toward an extension of the range and an increase in the accuracy of weather forecasts, and

WHEREAS, Encouraging results of this work in discovering new and better methods of forecasting the weather several days in advance have been reported on before the Section of Meteorology of the American Geophysical Union and these results have shown the outlook for long-range forecasts for the United States to be very hopeful, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council go on record as enthusiastically endorsing this work and urging upon the Congress that it be continued, and be it further

RESOLVED, That copies of this resolution be sent to the Secretary of Agriculture and to the Agricultural Subcommittees of the Senate and House Appropriations Committees.

(2) RESOLUTION ON THE GEOPHYSICAL AND GEOLOGICAL STUDY OF OCEANIC BASINS (submitted by Section of Seismology)

WHEREAS, The seismological work of the Special Committee on Geophysical and Geological Study of Oceanic Basins, under the chairmanship of Dr. Maurice Ewing, has already made valuable contributions to the science of seismology, and

WHEREAS, Continuation of this work is highly desirable, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council endorse these studies and encourage their further extension by the Special Committee and by other organizations, and be it further

RESOLVED, That a copy of this resolution be sent to the Chairman of the Special Committee on Geophysical and Geological Study of Oceanic Basins.

(3) RESOLUTION ON THE GEOPHYSICAL AND GEOLOGICAL STUDY OF CONTINENTS (submitted by Section of Seismology)

WHEREAS, The seismological work of the Special Committee on Geophysical and Geological Study of Continents, under the chairmanship of Dr. W. T. Thom, Jr., as well as similar work conducted by other persons, organizations, and institutions, has already made valuable contributions to the science of seismology, and

WHEREAS, Continuation of this work is highly desirable, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council endorse these studies and encourage their further pursuance and extension by the Special Committee and by other organizations and institutions, and be it further

RESOLVED, That a copy of this resolution be sent to the Chairman of the Special Committee on Geophysical and Geological Study of Continents.

(4) RESOLUTION ON SEISMOLOGICAL ACTIVITIES OF THE EASTERN SECTION OF THE SEISMOLOGICAL SOCIETY OF AMERICA (submitted by Section of Seismology)

WHEREAS, The work of the four committees of the Eastern Section of the Seismological Society of America on (1) Seismic Vault Construction, (2) Seismological Methods and Operations, (3) Amateur Seismology, and (4) Microseisms, is of value and importance to the science of seismology, therefore be it

RESOLVED, That the Section of Seismology of the American Geophysical Union and the Committee on Geophysics of the National Research Council endorse the activities of these Committees and express the hope that their activities will continue and, if possible, be enlarged, and be it further

RESOLVED, That copies of this resolution be sent to the President of the Seismological Society of America, to the Chairman of the Eastern Section, and to the chairmen of the Eastern Section's Committees on Seismic Vault Construction, Seismological Methods and Operations, Amateur Seismology, and Microseisms.

(5) RESOLUTION ON COOPERATION OF SMITHSONIAN INSTITUTION (submitted by Committee on Resolutions)

WHEREAS, The Smithsonian Institution generously granted facilities for meetings of the sections of Terrestrial Magnetism and Electricity and of Volcanology of the American Geophysical Union on Wednesday, April 26, 1939, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council thank the Smithsonian Institution for the assistance given, and be it further

RESOLVED, That a copy of this resolution be sent to the Secretary of the Smithsonian Institution.

(6) RESOLUTION ON COOPERATION OF GEORGE WASHINGTON UNIVERSITY (submitted by Committee on Resolutions)

WHEREAS, The George Washington University generously granted facilities for the Smoker of the American Geophysical Union on Thursday, April 27, 1939, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council express its appreciation of this courtesy extended by the George Washington University, and be it further

RESOLVED, That a copy of this resolution be sent to the President of George Washington University.

(7) RESOLUTION ON NAVAL OBSERVATORY TIME-SIGNALS (submitted by Committee on Resolutions)

WHEREAS, The time-signals transmitted by the United States Naval Observatory for every hour of the day are proving of inestimable advantage in many branches of geophysical observations, therefore be it

RESOLVED, That the American Geophysical Union and the Committee on Geophysics of the National Research Council hereby express to the Navy Department their appreciation and gratitude for such a complete service, and be it further

RESOLVED, That a copy of this resolution be sent to the President of the United States and to the Secretary of the Navy.

## Elections

The Section of Hydrology reported the election of the following officers for three years from July 1, 1939: N. C. Grover, President; M. P. O'Brien, Vice-President; K. H. Beij, Secretary. The Section of Seismology reported the election of Frank Neumann as Secretary for three years from July 1, 1939.

The meeting adjourned at 1:20 p.m.

## SCIENTIFIC SESSION

The scientific session, beginning at 2:38 p.m. with 84 members and guests present [see Appendix A], was devoted to a symposium on geophysical prospecting as printed in these Transactions [pp. 242-303]. Just preceding the presentation of papers, William Bowie was awarded the first copy of the Bowie Medal of the American Geophysical Union honoring unselfish cooperation in geophysical research (see memorandum following these minutes).

The Committee on Meetings [G. W. Musgrave (Chairman), H. N. Eaton, and R. T. Zoch] was commended for the excellent program developed which resulted in the great success of the twentieth annual meeting of the Union as evidenced by the papers published in this present volume of Transactions.

The meeting adjourned at 5:37 p.m.

The minutes of the meetings of the Sections of the American Geophysical Union, April 26-29, 1939, are given in attached Appendix G.

(Signed) Jno. A. Fleming, General Secretary,
American Geophysical Union

## MEMORANDUM REGARDING THE WILLIAM BOWIE MEDAL AND ITS FIRST AWARD

The William Bowie Medal, endowed by friends and coworkers of Dr. William Bowie, established by vote of the Executive Committee of the American Geophysical Union on March 1, 1939, in accordance with the deed of gift, is to be awarded for distinguished attainment and outstanding contribution to the advancement of cooperative research in fundamental geophysics. The Medal was designed by Margaret Fleming Nebeker, and the dies were engraved by B. Basch of Washington. The award of this Medal is to be made annually or less frequently upon authorization by the Executive Committee of the Union.

The first medal (see Fig. 1), which was struck off by the hydraulic press of the United States Bureau of Engraving through the courtesy of the Director, A. W. Hall, was presented to Dr.

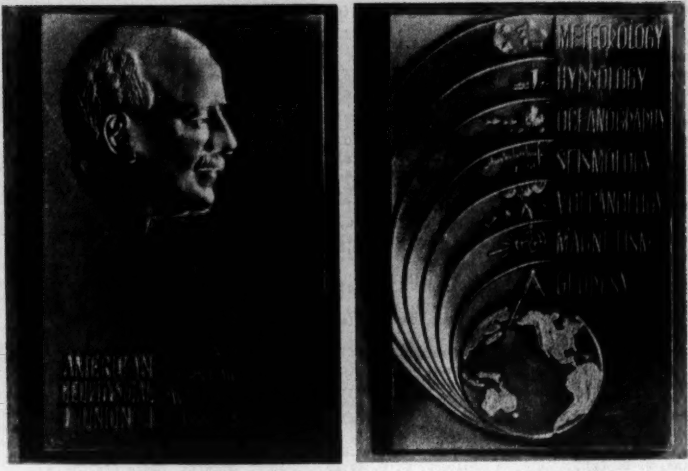

FIG. 1

Bowie at the general assembly of the Union on April 28, 1939, by President Richard M. Field. In his citation President Field said: "It is particularly fitting that the first award of this Medal should be to the man whose name the Medal bears. It is not necessary here, among your intimate friends and colleagues in geophysics to refer specifically to your long list of scientific accomplishments and honors. But we do feel that in presenting you with the first imprint of this Medal that has been created in your name, and that of the organization for which you have worked so long and so lovingly, we are not handing you merely a bit of stamped and engraved metal, but rather a powerful talisman of those human forces, affection, esteem, and tradition, so fundamental to the spirit of progress. It is sincerely hoped that in the years to come this Medal through its future awards will continue to promote and to recognize that spirit of helpfulness and friendliness in unselfish cooperative research which you have so bountifully displayed."

## APPENDIX A--RECORD OF 497 MEMBERS AND GUESTS WHO REGISTERED ATTENDANCE AT GENERAL ASSEMBLY OF THE UNION AND AT SESSIONS OF ITS SECTIONS, TWENTIETH ANNUAL MEETING, APRIL 26-29, 1939

(Total number in attendance was considerably in excess of those registered.)

(1 = Business session of General Assembly; 2 = Scientific session of General Assembly; a = Geodesy; b = Seismology; c = Meteorology; d = Terrestrial Magnetism and Electricity; e = Oceanography; f = Volcanology; and g = Hydrology.)

Adams, K. T. (e)
Adams, L. H. (f)
Adams, Oscar S. (2,a)
Affron, W. A. (e)
Aldrich, H. R. (d,f)
Allen, Alice S. (f)
Allen, E. T. (f)
Allen, R. A. (c)
Alpher, R. O. (1,2,a,e,f)
Anderson, B. J. (a,e)
Anderson, N. G. (c)
Arenberg, David (c)
Armstrong, W. E. (2,g)
Arnold, A. (b,c,d)
Aslakson, C. I. (e)
Avers, H. G. (a,e)
Bailey, R. K. (f)
Bainbridge, W. H. (e)
Baker, R. C. (g)
Baldwin, D. H. (a)
Baldwin, O. J. (g)
Balsam, E. (b,d,f)
Barksdale, H. C. (g)
Barnes, B. S. (g)
Barnes, F. F. (g)
Bates, R. E. (g)
Baumgartner, J. A. (g)
Bazzoni, C. B. (2)
Beij, K. H. (1,g)
Bemis, Alan C. (c)
Bernard, M. (g)
Bevan, A. (g)
Birch, Francis (a,b,f)
Bitter, F. (d)
Bitter, Mrs. Karl (d)
Bittinger, Charles (d)
Blaisdell, F. W. (g)
Blumenstroh, B. I. (g)
Blythe, John H. (e)
Bodle, R. R. (1,2,b,d)
Bollay, E. (g)
Bond, W. (2)

Bowen, N. L. (1,2,a,f)
Bowie, W. (1,b,e)
Boyer, M. C. (g)
Bradley, W. H. (d,e)
Brancato, G. N. (c,g)
Brillouin, L. (g)
Brooks, Charles F. (c)
Brown, A. L. (2,c,d,g)
Brown, C. B. (g)
Bucher, Walter H. (a,f)
Burbank, W. S. (f)
Burnett, E. L. (g)
Busse, Johanna (e)
Butterfield, A. D. (a,d)
Byers, H. R. (c)
Cady, R. C. (g)
Calkins, F. C. (f)
Callaghan, Eugene (2,f)
Cameron, D. C. (g)
Cannon, R. S., Jr. (f)
Capello, J. J. (1,2,b,d,e,f)
Claire, Charles N. (a)
Clayton, H. H. (c)
Clemence, G. M. (a)
Clifford, Charles J. (a)
Cochran, A. L. (g)
Cole, J. S. (g)
Cole, L. A. (e)
Collins, W. D. (g)
Connaughton, M. P. (a,g)
Conover, L. F. (c)
Converse, A. F. (2)
Converse, Elizabeth C. (2)
Cook, R. E. (g)
Cooke, H. L. (a)
Corry, J. (c)
Cory, H. T. (g)
Crawford, L. C. (g)
Cressey, George B. (a,c,e,g)
Criswell, W. H. (e)
Cronin, W. J. (e)
Culley, Frank L. (a)
Cumbuledge, A. A. (c)
Curtis, R. H. (c)
Davenport, R. W. (g)
Davis, A. L. (c)
Deetz, C. H. (a,e)
De Fabritis, L. L. (g)
De Golyer, E. (1,2)
Delaney, John P. (b)
Deyo, M. L. (e)
Dickerson, Roy E. (2,b,d,e,f)
Dobson, G. C. (g)
Doesing, C. J. (c)
Donley, D. E. (g)
Dorner, E. P. (e)
Dorsett, J. O. F. (c)
Dougherty, J. W. (g)
Dove, W. N. (2,d,f)
Drane, B. S. (g)
Duerksen, J. A. (2,a,e)
Duncan, Donald (f)
Du Pré, M. B. (g)
Duvall, C. R. (a,b,e,d)
Dye, Albert E. (e)
Eaton, H. N. (1,d,e,g)

Eicher, Maynard (c)
Eisenlohr, W. S., Jr. (g)
Eldridge, F. R., Jr. (c,d,f)
Ellis, E. P. (e)
Ellison, E. S. (c)
Ellison, W. A. (g)
Emmons, G. (c)
Ewing, Maurice (1,b,e)
Fairchild, John G. (f)
Fiedler, A. G. (g)
Field, R. M. (1,a,d,f)
Finney, E. P., Jr. (c)
Fishel, V. C. (g)
Flaxman, E. M. (a,g)
Fleischer, Michael (f)
Fleming, J. A. (1,2,b,c,d)
Fogel, E. H., Jr. (d)
Forbush, S. E. (d)
Frank, B. (g)
French, Owen B. (a)
Galvin, W. M. (c)
Gardner, L. S. (f)
Gareau, Paul A. (c)
Garner, C. L. (1,2,a,b,d)
Gartlein, C. W. (d)
Gartska, W. N. (g)
Geyer, Richard A. (a,f)
Gibbon, L. P. (1,2,a,e,g)
Gilbert, C. G. (c,g)
Gilchrist, L. (2)
Gilman, C. S. (g)
Gish, O. H. (1,2,d,f)
Gittings, E. B. (c)
Glass, Jewell J. (f)
Goddard, E. N. (f)
Goodall, W. M. (d)
Goodridge, R. S. (g)
Goranson, Roy W. (f)
Gracely, F. R. (d)
Grant, J. A. (g)
Graves, G. van A. (e)
Green, C. K. (e)
Greenwell, G. B. (a)
Greig, J. W. (2,a,f)
Griggs, David (f)
Griggs, R. F. (g)
Grimminger, G. (c)
Grover, N. C. (1,g)
Gruff, Ralph E. (c)
Gunn, Ross (f)
Guthe, O. E. (g)
Haase, B. J. (d)
Hafstad, K. C. (g)
Haight, F. J. (e)
Haines, W. C. (c)
Hamilton, W. (a)
Hand, Irving F. (c)
Harmantas, C. (c)
Harradon, H. D. (1,2,b,c,d)
Harrington, A. W. (g)
Harris, H. F. (g)
Harrison, L. P. (c)
Harrold, J. C. (g)
Harrold, L. L. (g)
Hathaway, G. A. (g)
Haurwitz, B. (d)

Hayes, H. C. (2)
Heck, N. H. (1,2,a,b,d,e)
Hellweg, J. F. (1,2,a,d)
Hemple, H. W. (2,a,e)
Hendrix, W. C. (2,d,f)
Henry, T. R. (2,c,d,e)
Hermansen, E. (g)
Hertzler, R. A. (g)
Hess, H. H. (b,e,f)
Holmes, G. W. (g)
Holzman, B. (c,g)
Hooper, L. J. (g)
Hoover, W. H. (d)
Horner, W. W. (g)
Horton, A. H. (g)
Horton, R. E. (g)
Howe, E. D. (f)
Howe, H. H. (1,d)
Howe, Mrs. H. H. (d)
Howland, Arthur L. (f)
Hoyt, W. G. (g)
Hubbert, M. K. (d,g)
Huddle, J. W. (d,e,g)
Huff, T. F. (d,f)
Hulburt, E. O. (d)
Humphreys, W. J. (c)
Hurd, Willis E. (c)
Hursh, C. R. (g)
Hurwitz, Louis (d)
Ingerson, Earl (f)
Isam, L. W. (c)
Iselin, C. O. (1,2,e)
Jacob, C. E. (g)
Jarvis, C. S. (g)
Johnson, E. A. (d)
Johnson, J. W. (g)
Johnson, T. H. (d)
Johnston, F. N. (e)
Johnston, H. F. (1,2,a,b,c,d,f)
Jones, B. E. (2,g)
Jones, Harris A. (c)
Jones, P. R. (c,g)
Jordan, C. R. (c)
Joyce, J. W. (1,2,b,d)
Judson, L. V. (2,a,e)
Kadel, B. C. (c)
Kahl, Joseph (1)
Kalinske, A. A. (g)
Katzin, M. (d)
Kaufman, H. P. (2,a,e)
Keevil, N. B. (d,f)
Keith, Arthur (2,b,d)
Kelly, S. F. (2,a,d,f,g)
Kennedy, W. D. (e)
Kenworthy, P. W. (c,g)
Kimball, B. F. (g)
King, A. L. (g)
Kirjasoff, L. S. (e)
Kirkham, D. (g)
Kittman, J. (e)
Klaer, F. H., Jr. (f,g)
Klepper, M. R. (2,g)
Kline, Alfred B. C. (c)
Knopf, Adolph (f)
Knopf, Eleanor B. (f)
Korff, S. A. (d)

Koschmann, A. H. (f)
Kosco, George I. (c)
Kracek, Frank C. (f)
Krauss, H. W. R. (e)
Kroll, C. W. (d)
Kutschenreuter, Paul H. (c)
Lambert, W. D. (1,2,a,b)
Landsberg, H. (1,2,b,c)
Lane, Alfred C. (f)
Lane, E. W. (g)
Langbein, W. B. (g)
Lapham, E. G. (c)
Larrabee, John H. (e)
Latham, W. J. (e)
Law, E. P. (g)
Ledig, P. G. (2,d)
Lee, F. W. (2,d)
Leggette, R. M. (2,g)
Lennahan, C. M. (c)
Lewis, G. (g)
Light, P. (g)
Linehan, Daniel (2,a,b,d)
Littlepage, G. B. (e)
Littman, J. (e)
Lloyd, J. R. (c)
Lockhart, W. M. (c)
Lohman, K. E. (e)
Lohman, S. W. (g)
Lorz, J. G. (d)
Losey, R. M. (c)
Loughlin, G. F. (2)
Lozo, F. E. (f)
Ludy, A. K. (2,b,d)
Macelwane, J. B. (1,2,a,b,d,f)
Mack, J. S. (c)
MacKaye, B. (g)
Maguire, B. J. (e)
Maher, J. C. (g)
Manns, E. N. (g)
Mansfield, G. R. (f)
Maris, H. B. (d)
Marmer, H. A. (e,g)
Martin, Lawrence (a,e,g)
Mason, M. A. (g)
Matthes, F. E. (g)
Mayhew, H. B. (e)
McCall, A. G. (g)
McComb, H. E. (1,2,b,d)
McCombs, Chas. (a)
McDonald, C. C. (g)
McDonald, J. M. (e)
McDonough, S. J. (d)
McGuinness, C. S. (g)
McKay, E. C. (e)
McNish, A. G. (1,2,d)
McQueen, H. R. (c)
Meade, B. K. (a)
Mears, A. H. (c)
Mears, I. T. (g)
Medina, Guillerma (e)
Meinzer, O. E. (1,g)
Melvin, E. H. (d)
Merriam, C. F. (g)
Meyer, R. F. (d)
Minogue, J. A. (a)
Mitchell, C. L. (c)
Mitchell, George S. (c)
Mitchell, Hugh C. (a)
Mitchell, R. L. (g)
Moats, P. L. (d)
Moore, A. Lee (a)
Morgan, H. R. (a)
Mousson, J. M. (g)
Murphy, John J. (c)
Murray, Harold W. (e)
Murto, H. C. (g)
Musgrave, G. W. (1,a,g)
Myers, A. J. (c,g)
Namias, J. (c)
Neal, O. R. (g)
Nelson, W. A. (a,d)
Ness, A. T. (g)
Neuberger, H. H. (2,b,c,d)
Neumann, F. (1,2,b)
Newcombe, C. L. (e)
Newlin, Delmas B. (a)
Nichols, R. C. (c)
Nichols, Robert L. (f)
O'Brien, Brian (d)
Osborn, E. T. (2)
Osborne, E. F. (f)
Osmun, J. (c)
Ould, R. S. (f)
Owen, J. C. (g)
Page, B. L. (a)
Pagliuca, S. (g)
Parkhurst, D. L. (e)
Parkin, Ernest J. (a)
Patnode, H. W. (g)
Patterson, G. W. (g)
Paul, D. M. (g)
Paulsen, C. G. (g)
Pawling, Jesse (a)
Peacock, F. L. (e)
Peoples, J. A. (2,e)
Peoples, Joe Webb (f)
Perkins, B., Jr. (2,b)
Peterson, B. J. (g)
Petretic, G. J. (g)
Pharo, Eugene (f)
Pierce, C. H. (g)
Pierce, W. G. (f)
Poling, A. C. (a)
Potter, Robert (d)
Potter, W. D. (g)
Powers, R. (c)
Pratt, Joseph H. (a,d,e,g)
Ramser, C. E. (g)
Ranneft, J. E. M. (e)
Ranny, G. L. (c)
Reading, O. S. (a,e)
Reichelderfer, F. W. (c)
Reynolds, Walter F. (a)
Rice, D. A. (a)
Richards, F. G. (e)
Riesbol, H. S. (g)
Ringland, A. C. (g)
Ritchie, D. C. (2,a)
Robertson, James (a)
Robinson, T. W. (g)
Rockwood, H. (c,g)
Rodgers, John (a,f)
Roman, Irwin (2,a,b,d,g)
Rooney, W. J. (1,2,d,e)
Ross, Clarence S. (f)
Rubey, W. W. (2,a)
Saltsman, E. (c)
Samuels, L. T. (c)
Samuels, L. M. (a,e)
Saville, T. (g)
Sayre, A. N. (g)
Schaller, W. T. (f)
Schairer, J. F. (f)
Schell, I. I. (c)
Schmehl, Francis F. (f)
Schworm, S. S. (c)
Scott, W. E. (2,a,b,c,d)
Scully, Charles B. (e)
Seaton, S. L. (d)
Seiwell, H. R. (1,e)
Serby, D. K. (g)
Shands, A. L. (c,g)
Shaw, H. S. (a)
Shepherd, B. B. (e)
Shepard, E. R. (2,a,b,g)
Sherman, K. L. (2,d)
Sherman, L. K. (g)
Sherry, B. J. (c)
Shofnos, William (e)
Showalter, A. K. (c,g)
Sims, G. H. (g)
Singer, A. D. (2,d,f)
Small, J. B. (a)
Smith, N. (d)
Smith, W. E. (g)
Snoddy, L. B. (d)
Snowman, Lewis G. (e)
Snyder, F. F. (g)
Solat, D. B. (c)
Soroka, M. O. (g)
Southwick, T. S. (c,g)
Spencer, A. C. (d)
Spencer, R. E. (c,g)
Spiegler, B. (c)
Spilhaus, A. F. (c)
Stair, R. (c)
Stanton, H. E. (b,d)
Steare, R. C. (c)
Stearns, Charles E. (f)
Stearn, J. L. (a)
Steele, J. G. (g)
Steiner, W. F. (2,d)
Stephenson, E. B. (2,e)
Stetson, H. T. (1,2,a,b,d)
Stevens, G. C. (g)
Stevens, R. E. (f)
Stickley, A. R. (c)
Stipp, J. R. (a)
Stoker, W. L. (f)
Stone, G. R. (c)
Straley, H. W. (d,e)
Straub, L. G. (g)
Stringfield, V. T. (2,g)
Sundstrom, R. W. (g)
Sutcliffe, W. D. (a)
Sverdrup, H. U. (d,e)
Swainson, O. W. (b,e)
Swartz, J. H. (2,d)

Sweet, J. S. (g)
Swenson, B. (c)
Swick, C. H. (1,2,a,d,e)
Sykes, Lloyd (c)
Sykes, R. A. (2)
Tannehill, I. R. (c)
Thom, H. C. S. (g)
Thom, W. T., Jr. (1,2,a,d)
Thomas, L. F. (c)
Thompson, D. G. (2,g)
Thone, E. D. (d)
Thornthwaite, C. W. (c,g)
Tibbott, E. W. (a)
Todd, F. C. (2)
Torreson, O. W. (2,b,c,d)
Trask, P. D. (1,2,e,g)
Trevor, B. (d)
Tunell, G. (f)
Turner, Francis J. (f)
Turner, S. F. (2,g)
Uhland, R. E. (g)
Vacquier, V. (1,2,a,b,d)
Van Orstrand, C. E. (2)
Vaughan, T. Wayland (1,e)
Vestine, E. H. (b,d)
Vhay, J. S. (f)
Vine, Allyn (2,a,b,e)
Wait, G. R. (2,b,d)
Wallis, W. F. (2,d)
Walstrom, A. W. (c)
Warren, W. C. (f)
Watt, W. G. (c,e)
Weightman, R. H. (c)
Welden, J. B. (a,e)
Wells, Francis G. (f)
Wells, Roger C. (f)
Wenzel, L. K. (g)
Wexler, H. (c)
Whitcomb, Lawrence (a)
White, D. E. (f,g)
Whitten, C. A. (2,a,e)
Wiggin, B. L. (c)
Willett, H. C. (c)
Williamson, P. H. (d)
Williamson, R. O. (a)
Wilm, H. G. (g)
Wilson, H. G. (g)
Wilson, R. M. (a)
Wolfe, P. E. (g)
Woo, C. (g)
Woollard, Eleanor M. (2,a)
Woollard, G. P. (2,a)
Woster, H. C. (g)
Wright, F. E. (2,a,c)
Wulf, Oliver R. (b,c,d)
Yagman, B. (a)
Zies, E. G. (1,2,d,f)
Zimmerman, D. Z. (c)
Zoch, Richmond T. (c)

## APPENDIX B--REPORT OF THE GENERAL SECRETARY OF THE AMERICAN GEOPHYSICAL UNION TO THE GENERAL ASSEMBLY, TWENTIETH ANNUAL MEETING, APRIL 28, 1939

The minutes of the nineteenth annual meeting held April 29, 1938, were printed in the Transactions of that meeting (Part I, pp. 563-565) and distributed to all members of the Union, to authors of papers presented at the meeting, and to officers of the International Union of Geodesy and Geophysics. No suggestions for changes or corrections have been received. The General Secretary reported on the nineteenth annual meeting in Science of September 23, 1938.

Since April 29, 1938, four members of the Union have died. Fred H. Tibbetts, August 2, 1938, affiliated with the sections of Meteorology and Hydrology; W. R. Gregg, September 14, 1938, affiliated with the sections of Meteorology, Terrestrial Magnetism and Electricity, and Hydrology; Frederick J. Pack, December 3, 1938, affiliated with all sections; A. C. Veatch, December 24, 1938, affiliated with the Section of Oceanography.

The total membership of the Union April 28, 1939, is 1124--a net gain of 117 during the past year. An alphabetical address-list of members showing also their affiliations with sections was prepared and distributed to all members as of date February 15, 1939.

The Executive Committee held two meetings since the last report (September 23, 1938, and January 14, 1939). Copies of the minutes of these meetings were distributed to members of the Executive Committee and to officers of the sections.

The necessary arrangements were made for the twentieth annual meetings of the Union and of its sections in Washington April 26, 27, and 28, 1939, the program for the scientific sessions including some 90 papers and progress-reports. A smoker for the whole Union was held in the evening of April 27 at the George Washington University and was attended by 100 members and guests.

The General Secretary edited and prepared for publication--after some preliminary editing by the secretaries of sections and by J. E. Church and F. J. Veihmeyer for the regional meetings--140 papers and reports for the nineteenth annual meeting at Washington contained in Part I (pp. 1-585) and some 38 papers and reports (not elsewhere published) with discussions presented during the meetings of the Section of Hydrology and of the Western Interstate Snow-Survey Conference at Spokane and Davis contained in Part II (pp. 586-745). Because of the importance of the minutes of the General Assembly and of those of the sections, with their appendices, in the general view of the development of the Union and of their interest to all of its members, they were included, for the first time, as a part of these Transactions. Included in these minutes are the reports of officers and of standing, special, and research committees. The cost of publication was met through allotment by the National Research Council for maintenance of the Union, annual dues of members, and contributions of money and of services from the Carnegie Institution of Washington, from the University of Nevada, from members of the Union, and especially from hydrologists including both members and non-members. Eighteen hundred bound copies of these Transactions were planographed. Over 1750 copies have been distributed to members of the Union, to authors of papers presented, to foreign geophysicsts including members and non-members of national committees for geodesy and geophysics, to institutions and scientific societies, to review periodicals, to persons on the regular mailing-list of the National Research Council, and by sale. An unusually large number of reprints were purchased by authors.

The Executive Committee has approved a change in the present method of publication of the Transactions so that individual articles may be published promptly when manuscripts are received under the title "Transactions of the American Geophysical Union," to be paged continuously for each year with distribution at more or less regular intervals. The Transactions for 1939 will be published in four parts to include the papers and reports presented (I) at the regional meetings of the Section of Hydrology during December 1938, (II) in symposium on floods at twentieth annual meeting, (III) at general session and all sections except Hydrology at the twentieth annual meeting, and (IV) at meetings of Section of Hydrology at twentieth annual meeting.

A regional meeting of the Union's Section of Hydrology at the University of California, Los Angeles, California, December 16 and 17, 1938, was held in affiliation with the Western Interstate Snow-Survey Conference. Fourteen papers on hydrologic problems related to flood-control were presented at three sessions of the Section during those two days. Sixteen papers on problems in snow-surveying were presented before the Western Interstate Snow-Survey Conference in the evening of December 16.

The Section of Hydrology of the Union and the Western Interstate Snow-Survey Conference held a regional meeting at Spokane, Washington, December 29, 1938, in affiliation with the Northwest Scientific Association, at which reports and papers were presented on snow-survey problems and the effect of soil-priming by fall precipitation on spring runoff. This meeting was concluded with a round-table discussion of the above themes.

A Bibliography of Hydrology of the United States for the year 1937 (68 pages) was compiled by the Secretary of the Section of Hydrology and 1200 copies were planographed from master-copy prepared in the General Secretary's office. Five hundred copies were furnished to the Secretary of the International Association of Scientific Hydrology for incorporation in the International Bibliography and one copy was forwarded to each member of the Section of Hydrology of the American Geophysical Union.

On December 27, 1938, at Richmond, Virginia, the American Geophysical Union and sections D (Astronomy) and E (Geology and Geography) of the American Association for the Advancement of Science took part in a stimulating and interesting symposium arranged by W. T. Thom, Jr., on "The importance of geophysics to the study of continental borders," at which eight papers were presented by members of the Union.

The National Research Council has included in its estimates for the fiscal year ending June 30, 1940, a grant of $400 to the Union. After consulting with the General Secretary's office, a budget totaling $6600 has been submitted by the Budget Committee of the Union for expenses of publication and maintenance during that fiscal year. The estimated income includes: (1) Balance in bank, July 1, 1939, $1000; income from 1939 dues, $3400; (3) grant from National Research Council, $400; (4) sales of Transactions and reprints, $1800.

An Auditing Committee examined the accounts of the Union as of date December 31, 1938, and reported the receipts and disbursements exactly as stated in the General Secretary's report of that date.

A new edition of the Statutes and By-Laws of our Union as amended to April 29, 1938, was distributed to all members of the Union.

The Union continued its cooperation with the Division of Physical Sciences of the National Research Council in the preparation of special bulletins on geophysical methods, instruments, results, etc. Page-proof for volume VIII of the series "Physics of the Earth" of the National Research Council entitled "Terrestrial magnetism and electricity" has been practically completed by the McGraw-Hill Book Company of New York, and it is expected that this volume of some 800 printed pages will issue in August, 1939. Volume VII of the series entitled "The internal constitution of the Earth" is also being printed by the McGraw-Hill Book Company; it contains 413 pages and is expected to issue early in July, 1939.

A Special Committee on Cosmic Terrestrial Relationships to supplement the work of the Special Committees on the Geophysical and Geological Study of Oceanic Basins and of Continents was approved by the Executive Committee on January 14, 1939. Its function is to investigate all possible effects of extra-terrestrial bodies on the lithosphere, hydrosphere, and atmosphere of the Earth by (1) a comprehensive evaluation of observational data and methods and (2) consideration of both the method and means of acquiring further experimental and observational data. Such a committee is deemed to be of the utmost importance to major problems in geodesy and structural geology.

The Special Committee on Geophysical and Geological Study of Continents reports that the Dominion Observatory of Canada is completing two gravity-profiles in order to continue the recently developed New England gravity-picture. Similarly, through collaboration of the Special Committees on Geophysical and Geological Study of Oceanic Basins and of Continents with the State Geologist of New Jersey, two seismic traverses normal to the shore-line have been run and pendulum-profiles have been established from Plansboro to Normandy Beach and from Chester to Avalon (near Atlantic City), which give satisfactory indications as to the depth and character of the basement-surface and of certain zones in the superjacent sediments and show systematic regional variations in gravity which apparently are reflections of the major crustal structures of the area. At the request of this Committee and others, the United States Coast and Geodetic Survey has completed a series of gravity-profiles in southeastern Pennsylvania, in Delaware, in the Eastern Shore Region of Maryland and Virginia, in eastern North Carolina and southeastern Virginia, and in southern Georgia and northern Florida. From an inspection of these data it is obvious that there is a systematic correlation between the gravity-profiles and regional crustal structures, with suggestions as to the existence of greater local stress-conditions in crust in certain coastal areas than had previously been supposed. An additional effect of all this work has been to create a series of primary gravity reference-stations within the regions studied. Members of the Committee have also been active in collecting maps, well-records, and other data bearing on the geophysical methods and appliances which are especially promising for geophysical-geological study of continental areas. The Committee is compiling and analyzing data whereby a new relief-model of the basement-surface of a large part of the United States will be constructed as a background for a collection of regional and local geophysical-geological maps which will illustrate how the presence and nature of concealed geologic structures have been revealed by different geophysical exploratory methods.

It is a pleasure to report that the non-magnetic ship *Research* constructed by the British Admiralty was launched April 4, 1939; it is hoped she may be in commission by February, 1940. This vessel will continue the magnetic and electric surveys of the oceans done by the *Carnegie* during 1909-29.

The Union maintained its relations with the international body. Preparations are well advanced for the Seventh Triennial Assembly of the International Union of Geodesy and Geophysics to be held at Washington in September 1939. The second circular to all delegates and guests, a special circular to American delegates and guests, a list of acceptances from delegates and guests through March 31, 1939, full memberships of the committees on arrangements of the American Geophysical Union, and other pertinent matter were planographed under date of March 31, 1939, and distributed to the representatives of governments and organizations adhering to the International Union of Geodesy and Geophysics, to all other governments and organizations interested in geodesy and geophysics, and to all members of the American Geophysical Union. At date, the acceptances total 315 delegates and guests and 46 ladies. The letters received through our State Department in answer to the original circular to the various governments which were invited to attend through our diplomatic missions in all nations indicate that many of them, in addition to those which have already accepted, are considering the appointment of official delegates. Thus the Washington Assembly promises to have large and wide-spread representation. Substantial grants toward the expenses of the Assembly have been received from the National Research Council, the Geological Society of America, and the Carnegie Corporation of New York; these, in connection with the individual contributions of members of the American Geophysical Union and friends by cash and pledges, as well as by promises of services, augur well for a successful Assembly.

The dues of the United States for 1938 as an adhering member of the International Council of Scientific Unions have been paid and steps are now being taken to make available funds to cover the dues for 1934, already authorized by Congress.

The contributions of the American Geophysical Union through its coordination of many agencies afford ample evidence of the scientific and economic value of geophysical research. Further substantial progress may be confidently expected through the activities of the special committees of the Union and of its sections.

(Signed) Jno. A. Fleming, General Secretary
American Geophysical Union

## APPENDIX C--REPORT OF SPECIAL COMMITTEE ON GEOPHYSICAL AND GEOLOGICAL STUDY OF OCEANIC BASINS

Maurice Ewing, Chairman
H. H. Hess, Secretary

D. C. Barton
F. Birch
J. Boyd
W. H. Bradley
W. H. Bucher
L. O. Colbert
E. G. Conklin
R. E. Dickerson
E. A. Eckhardt
J. A. Fleming
B. Gutenberg
N. H. Heck
C. O. Iselin
H. Landsberg
L. R. Leahy
P. MacClintock
A. G. McNish
W. A. Nelson
C. S. Piggot
L. A. Richards
W. W. Rubey
F. P. Shepard
P. A. Smith
F. M. Soule
H. C. Stetson
H. T. Stetson
H. U. Sverdrup
C. H. Swick
W. T. Thom, Jr.
T. G. Thompson
P. Weaver
F. E. Wright
A. C. Veatch (deceased)

During the past year the trend toward increased emphasis of the international aspects of the geophysical exploration of oceanic basins has continued. Through the agency of the Commission on Continental and Oceanic Structure of the International Union of Geodesy and Geophysics, this Committee has been able to play its part in international cooperation. Instances of this cooperative effort are the establishment of the Bermuda Seismograph Station and the program of seismic measurements which were made on board the research vessel Culver of the Royal Society.

Activities for the past year reported by individual members of the Committee are as follows:

(1) L. O. Colbert, N. H. Heck, and P. A. Smith

(a) Oceanography--The matter of contributions to oceanography and tides and currents by the Coast and Geodetic Survey will be discussed before the Section of Oceanography by L. O. Colbert, and the paper will be published in the Transactions of the American Geophysical Union (see pp. 410-412).

The paper points out the nature of the contributions respecting submarine topography of the coastal regions surveyed, the large quantity of accurate data obtained in the course of the past few years through surveys for nautical charts, and a few of the major problems and broader questions now confronting marine surveyors and cartographers. An outline is also given of the primary tidal stations maintained during the past year about the coasts of the United States and possessions and the current-observations that are being made together with the bearing that the tide and current-observations have on the subject of oceanography in general. A detailed report of the progress of coastal surveys will be included.

(b) Terrestrial magnetism or geomagnetism--Dr. S. Chapman has recently suggested the use of the word "geomagnetism" to replace the established hybrid expression (from Latin and Greek) "terrestrial magnetism"; and this new word should come into general use, even if the latter expression is retained for certain purposes.

The contribution of the Coast and Geodetic Survey to geomagnetism as it relates to the geology of the oceanic basins is through the operation of five magnetic observatories, all of which, except that at Tucson, Arizona, are quite near the coasts (Puerto Rico, Maryland, Alaska, and Hawaii); also by observations along the coasts both to determine secular change and to outline areas of local magnetic disturbance, and especially to insure the proper values on the mariners' charts. This latter work is of special importance in Alaska including the Aleutian Islands. A few observations made at sea by means of a whale-boat merely emphasized the need for detailed observations by a non-magnetic vessel.

The special contribution of the Coast and Geodetic Survey consists in improving the instruments and methods at a number of the observatories, especially Hawaii and Puerto Rico, and in the use of new instruments for comparisons between the observatories. Several new instruments which have recently come into use are described in a paper by H. E. McComb and J. W. Joyce for the Section of Terrestrial Magnetism and Electricity.

As indicated, the great need is for magnetic observations at sea, a need which can only be partly met by the British vessel Research. The United States should by all means have a small non-magnetic vessel of its own.

(c) Seismology--The contribution of the Coast and Geodetic Survey to seismology has been in the operation of seismograph-stations in the vicinity of the coasts so as to make it possible to study the transmission of waves beneath the oceanic basins without conclusions being too much weakened by a long path of travel beneath the land. In this connection, the cooperative station at Columbia, South Carolina, the station at San Juan, Puerto Rico, and that at Balboa, Canal Zone, are particularly useful. However, perhaps the most important contribution in connection with the Atlantic Basin is being rendered through the establishment of the Bermuda Seismograph-Station, which makes it possible to record the waves passing over the Atlantic path from the Middle Atlantic Region to Bermuda.

In the case of the Pacific Ocean, the Bureau contribution to the operation of a number of important seismograph-stations, notably Tucson (Arizona), Sitka (Alaska), Ukiah (California), College (near Fairbanks, Alaska), and Honolulu (Hawaii), bears a similar relation to the Pacific that Bermuda does to the Atlantic. The Balboa station is equally concerned with the Pacific and cooperates and helps in the interpretation of the important stations of the Carnegie Institution of Washington at Huancayo, Peru, and that of the Smithsonian Institution at Mount Montezuma, Chile.

The future need in both of these fields is for more intensive observations. There is particular need for the study of the nature of the geological change in the rim of the Pacific and, in the case of the Atlantic, determinations of the thickness of the crust. Other seismological problems are outlined in a paper entitled "The role of earthquakes and the seismic method in submarine geology" by N. H. Heck [Proc. Amer. Phil. Soc., v. 79, No. 1, April, 1938].

(2) C. H. Swick

The isostatic reductions of seven gravity-at-sea stations determined by Dr. Meinesz in 1938 in the southern part of the Caribbean Sea have been made by the Coast and Geodetic Survey.

The Government of Venezuela has made the necessary appropriation to cover the proposed cooperative gravity-survey and has requested cooperation. The work may possibly be started in December. This work is of interest for the study of oceanic basins because of its relation to the adjacent gravity-at-sea surveys.

(3) H. Landsberg

Drs. Landsberg and Neuberger have finished during the past year an investigation on the travel-time curves of $P_n$-waves. The paper on the results will be presented before the seventh assembly of the International Union of Geodesy and Geophysics in Washington. There are some indications that the travel-times in the sub-Pacific Area are slightly less than elsewhere. This would be in agreement with a similar contention of Jeffreys, but we are not 100 per cent certain of this deduction because of the unfortunate distribution of stations over the surface of the Earth. They propose to continue their investigations and make use of fast surface-waves also. They hope to concentrate especially on data from the Atlantic and especially to see what transitions, if any, take place at the oceanic continental border.

(4) H. U. Sverdrup

Extensive investigations of the submarine topography off southern California were conducted in 1938 by Dr. F. P. Shepard who, thanks to a grant from the Geological Society of America, had at his disposal the research vessel E. W. Scripps in alternate months. During the cruises a large number of rock-samples were dredged from the bottom and a number of cores of bottom-sediments were obtained. Current-measurements were made at distances of 20 to 50 cm from the bottom by means of a current-meter which was suspended from a tripod. Dr. Shepard will undoubtedly report in detail on these investigations which were conducted in part in cooperation with Dr. Roger Revelle of the Scripps Institution of Oceanography. The collected cores are being examined by Dr. Revelle at the Scripps Institution, where chemical and mechanical analyses are being conducted.

In February and March, 1939, the E. W. Scripps made a cruise to the Gulf of California during which about 2500 soundings by fathometer were made when travelling 2200 miles. Ten complete profiles were run across the Gulf. The soundings have not yet been examined and mention will, therefore, be made only of the fact that in the inner portion of the Gulf between the peninsula and the group of islands extending between San Lorenzo Island in the south and Angel de la Guardia in the north, a trough was found with a maximum depth of 860 fathoms. This trough is separated from the depths in the outer portion of the Gulf by a sill which probably runs south-southwest from Tiburon Island with a saddle-depth of about 150 fathoms.

On the cruise about 50 cores of bottom-sediments were collected ranging in length from a few inches up to more than nine feet. The localities from which cores were obtained lie between latitudes 23° north and 31° 15' north. These cores are being analyzed in the laboratories of the Scripps Institution of Oceanography.

(5) C. S. Piggot

The deep-sea sounding winch is not yet in condition to take to sea but, it is hoped, will be ready for deep-water trials by some time in July. It is also hoped that it may be tested on a cable-ship during August, 1939.

There are now five institutions in the United States and Europe using this core-sampler developed by Piggot, apparently with satisfactory results. The report of the scientific studies of the North Atlantic cores will be published shortly.

(6) P. MacClintock

(a) Further work was accomplished by one of our students on the problem of coastal lagoons and offshore bars. The results confirm the opinion that such features have resulted from processes of drowning rather than emergence.

(b) Work of Meinesz suggests effective wave-erosion and transportation at depths of 100 meters and more. But no measurements of wave-action on the bottom at such depths have ever been attempted. Would it not be a highly significant piece of research to devise instruments and a program to find out what wave-action may be taking place on the edge of the continental shelf?

(7) H. H. Hess

(a) The bathymetric chart prepared in cooperation with the Hydrographic Office has now been printed and can be purchased from the Hydrographic Office. It represents soundings taken by 90 cruises of United States Navy vessels, by the Atlantis, by H.M.S. Challenger, and by others. It is the most accurate and detailed presentation of deep-sea topography for large areas far from land which has been made. Much credit is due the Hydrographic Office for this valuable scientific contribution.

(b) A grant for further gravity-at-sea work has been obtained from the American Philosophical Society and plans for constructing an instrument are progressing. Dr. Vening Meinesz has kindly offered his services in advising us on building of new apparatus.

(c) Dr. Hess will make a geological reconnaissance in Venezuela this summer of the area included in the proposed land gravity-survey and also of the islands off the Venezuelan Coast where gravity-at-sea profiles are to be run.

(8) M. Ewing

(a) Progress in seismic measurements on the oceanic floor has been quickened through addition of support from the John Simon Guggenheim Memorial Foundation to that received from the Penrose Fund of the Geological Society of America. In September, 1938, a cruise on board the Atlantis resulted in perfection of a rubber bomb-shell which is less expensive and more convenient than the steel ones used previously. In October and November, 1938, a new set of seismic apparatus was constructed. In the new set, floats filled with gasoline are used instead of wires to bring the apparatus to the surface. Final development and testing of the new apparatus were made during December, 1938, to April, 1939, on board the research vessel Culver at the Bermuda Biological Station.

(b) Through cooperation of the Commission on Continental and Oceanic Structure of the International Union of Geodesy and Geophysics, the United States Coast and Geodetic Survey, and the Bermuda Meteorological Station, a seismograph-station was set in operation in Bermuda in February, 1939.

Lehigh University,
    Bethlehem, Pennsylvania

## APPENDIX D--REPORT OF SPECIAL COMMITTEE ON COSMIC TERRESTRIAL RELATIONSHIPS

Harlan True Stetson, Chairman

Wm. Bowie
C. F. Brooks
H. H. Clayton
A. E. Douglass
Maurice Ewing
J. A. Fleming
N. H. Heck
J. F. Hellweg
E. A. Hodgson
J. Kaplan
G. W. Kenrick
W. D. Lambert
A. C. Lane
H. R. Morgan
F. R. Moulton
G. W. Pickard
Paul Sollenberger
J. Q. Stewart
W. T. Thom, Jr.

So many problems concerning the nature and structure of our Earth cross the conventional compartments into which technical work has become segregated that even such divergent fields as astronomy, geology, meteorology, and engineering may be expected to yield invaluable elements in a comprehensive geophysical approach to Earth science. Excellent examples of coordinated interests in geophysics requiring the closest cooperation are the Special Committees of the American Geophysical Union--one on the Geophysical and Geological Study of Continents and the other on the Geophysical and Geological Study of Oceanic Basins.

It is because of the fact that in canvassing every avenue of approach to certain problems encountered by these committees that a third Special Committee of the American Geophysical Union has recently been formed. It is hoped that an investigation of such material as now exists or may yet be acquired will add information concerning the part that extra-terrestrial forces may play in geophysical phenomena. There is much evidence of changes taking place in the Earth and its atmosphere for which satisfactory explanations do not appear to be forthcoming in the study of the Earth alone.

This Special Committee on Cosmic Terrestrial Relationships is informed that its particular function will be to investigate all possible effects of extra-terrestrial bodies on the lithosphere, hydrosphere, and atmosphere of the Earth by (1) attempting a comprehensive evaluation of observational data and methods, and (2) giving consideration to both the methods and the means of acquiring further experimental and observational data.

Since this Committee was especially appointed for the purpose of supplementing the Committee on the Geophysical and Geological Study of Oceanic Basins and the Special Committee on the Geophysical and Geological Study of Continents, it has been requested that, at least at the outset, our Committee devote its attention to such specific data as may bear upon the question of the origin and detecting of movements of the crustal structure where extra-terrestrial factors or observations may be concerned.

Whatever success the Committee may hope to achieve must depend not only upon extensive cooperation but upon the approach to its problems without prejudice to any theory or anticipating verification of any preconceived interpretations.

As the nature of the basement-complex underlying continents and oceans and the question of translatory movements in the Earth's crust are of vital consequence in structural geology, geophysics in its broader aspects should find every available source of data that may be helpful in extending our information in these directions. The accumulating evidence for continued, yet intermittent, migrations of land-masses irrespective of the amount, and the existence of certain unaccountable variations in geographic coordinates determined from astronomical observations suggest that serious consideration should be given to any interrelation that may appear to exist. Geologists have long sought for astronomical evidence for shifts in land-masses. On this subject observations have been conflicting and disappointing. An examination of systematic distributions, in which "errors of observation" are generally regarded as inevitable, may add light to the problems or at least suggest certain directions in which increased precision may be obtained. It seems desirable, before discussing existing data relative to variations in geographic coordinates and the degree of reliability which may be placed upon them, to summarize from the point of view of the structural geologist the evidence that the Earth itself affords regarding crustal movements. Professor W. T. Thom, Jr., Chairman of the Special Committee on the Geophysical and Geological Study of Continents, has furnished your Committee with valuable material which is summarized below.

### Geological evidence for crustal movements

(1) Geologic study of the crustal structure of the Earth gives evidence for some force or agency causing crustal deformation that has been operative since pre-Cambrian times. The indication of recurrent mountain-building episodes suggests that the results of such forces as have

been operative have been intermittent, migratory, and marked with more or less rhythm.

(2) Observations of fracturing, thrust-faulting, and folding which make up the structural picture so familiar to geologists indicate that such superficial deformations involve a near-surface veneer of rock from 15 to 70 km in thickness.

(3) This veneer, which we may call the crust of the Earth, is relatively rigid and strong as compared to the asthenosphere or zone of isostatic compensation that appears to underlie the crust itself.

(4) The surface-features make it clear that the crust includes certain more rigid "shield"-areas. These areas, chiefly granitic in the case of continents, are conspicuous in the following areas: Canadian regions surrounding, and south of, Hudson's Bay; South America to the east and southeast of the Andes; Africa south of the Atlas Mountains; Arabia and India; the Scandinavian and the Russian platform-regions north of the Alps and northeast of the Carpathians and west of the Urals; the Angara shield of north-central Siberia; a sub-shield in the part of China lying east of Tibet; the Australasian shield south and southeast of the East Indian Island-Arc; and Antarctica. The probability seems great that suboceanic "shield"-areas also exist, but positive evidence of this can only come from the more adequate exploration of the oceanic bottoms.

(5) Between these shields, that is, peripheral to the continental shield-areas, belts have developed from time to time in which seismic disturbances and vulcanism have accompanied or preceded the crowding together of these strips of crust, or orogenic zones. Crumpling of an orogenic belt produces an arcuate mountain range, or island-arc, plus a fore-deep or geosyncline. With the development of such a fore-deep, it tends to become filled with clastic materials, eroded from the contiguous hinterland-uplift or mountain range; and with the crowding of this range against the trough-fill, the fill becomes first crumpled and then apparently shoved up on the margin of the shield in a series of folds and overthrusts.

(6) While there definitely have been recurrent episodes of mountain-building, the cycle can hardly be called rhythmic or periodic in any exact sense. But it would appear that recurrences of mountain-building may have taken place at fairly regular intervals of 30 to 40 million years. Within each major mountain-building episode there are evident many minor rhythms or cycles of elevations of the hinterland, accompanied by sympathetic depression in the trough or basin of down-folding, and an obvious crowding of the hinterland towards the trough or "orogen" thus developed. The time required for a mountain-building episode--a million years or so--is relatively brief as compared to the interval of 30 to 40 million years between orogenic maxima. Sub-rhythms of the major episodes have apparently occurred at intervals of perhaps 10,000 to 100,000 years. Still shorter intervals between earth-movements are recognized by periods of marked seismic disturbances at intervals as brief as tens or hundreds of years. Such recurrences of activity are suggestive of the relief of accumulated stress which may be due to the persistence of small forces acting continuously or intermittently in a given direction.

The crustal shortening, as measured by the horizontal overthrusting occurring within one major mountain-building episode, may amount to as much as 25 to 50 miles as a minimum in a given orogenic period. Some authorities, not satisfied with so conservative a statement, would claim a crustal shortening measured in hundreds rather than tens of miles in a given period.

While translatory movements have been taking place, evidence abounds for vertical changes. Changes of level now going on are of course most in evidence in regions of instability. Every marked seismic catastrophe affords an exhibition of both lateral and vertical displacements. Measurable changes in level, however, take place in certain regions even when not accompanied by conspicuous earthquake-activity. A Japanese survey in the vicinity of Ito has revealed changes of level of five to eight inches over the interval from 1930 to 1933. Researches with the new form of gravimeter recently developed at the Gulf Laboratories have demonstrated earth-tides with an apparent rise and fall of the order of a foot during the lunar day. Removal of the uncertainty in the amplitude involved awaits a more complete calibration of the gravimeter.

With the accumulating evidence for mobility in the Earth's crust, it is not surprising that structural geology turns to geophysics and astronomy for inquiry as to the possibility of extra-terrestrial origin of forces that may be operative, or for information from geodetic measurements as to the magnitude and direction of such movements as may be detected from astronomical observation.

Tidal forces exerted by the Moon and Sun offer, so far as is known, the only appreciable potentials of extra-terrestrial origin that can enter into the problem. Such forces at best are so small compared with the forces that have been at work in mountain-building and crustal deformation in geological time that, at least thus far, little encouragement has been found from the examination of such disturbing factors from outside the Earth. The fact that earth-tides do exist and that accumulating stresses may ultimately play a part in earth-movements, however, must continuously be kept in mind. A recent survey of earthquake-frequencies as related to the lunar hour-angle offers some little support for the deductions that accumulating tidal stresses may at least be a help in the precipitation of seismic events, especially where earthquakes of deep focus are concerned [see 1 of "References" at end of report].

## Astronomical evidence for variation in geographic coordinates

Reflecting upon the above facts, geodesists and astronomers naturally have become interested in intercomparing observations of position for any given station after lapsed intervals to determine what, if any, migratory movements of the land may have taken place between periods of observation. The controversy over the Wegener hypothesis of continental drift at least served as a stimulus to astronomical investigations of change in position. Old and new surveys were intercompared--latitudes and longitudes of known points were reobserved, often with conflicting results but with no definite assurance of land-migrations of the order of magnitude demanded by the proponents of the Wegener hypothesis [2]. With the passing of the more heated stage of the controversy, there is time to reexamine astronomical data without prejudice as to any anticipated results.

Considering all the evidence for crustal movement which geology has gathered, it is perhaps somewhat surprising that the intercomparison of astronomical determinations of latitude and longitude over a period of years have revealed so little evidence for some change that would not fall within the range of the inevitable errors of observation. A study of these observational errors, on the other hand, may yet reveal sources of systematic differences which may give some clue to their origin. With the best of modern equipment, a series of astronomical observations at a given station should locate the geographical coordinates of the point occupied with an accuracy of less than half a meter in latitude and one to two meters in longitude--an ideal of precision seldom attained in practice due to atmospheric refraction and turbulence that disturbs the light from the star under observation. Nevertheless, in averaging large numbers of observations made under all sorts of meteorological conditions, non-periodic differences have a way of eliminating themselves. The now well-recognized motion of the Earth's pole of rotation about its pole-of-figure was brought to light in the latter part of the nineteenth century by periodic variations of latitude amounting to but a few meters as measured on the great-circle arc. The length of this period of latitude-variation, marked by Chandler as 428 days, was so discordant with the theoretical period of 310 days predicted by Euler for a rigid body that the discrepancy made possible an evaluation of the deformation of the Earth's figure due to the changed accelerations involved. The establishment in 1899 of a series of latitude-stations on the parallel of 39° 08' by the International Geodetic Association made possible the continued study of the wandering of the terrestrial pole and at the same time revealed variations still to be accounted for that may yet yield information of geophysical interest.

A study of these residuals in latitude-variations after the known motion of the pole has been removed suggests certain dependence of these variations upon the Moon's position which would appear to link the importance of such astronomical observations to the geophysical problem of earth-tides--a subject that has occupied a Commission of the International Union of which Dr. Lambert, a member of our Special Committee, has proved an able reporter [3]. Certain inconsistencies and changes of phase in the behavior of latitude-residuals, depending upon the region of the Globe and the period over which the observations have been examined, complicate the problem but may suggest that we shall have to entertain the possibility that irregular and regional oscillatory movements take place with migratory tendencies over longer periods of time.

In the reductions of the observations of the International Latitude Service of 1923 to 1931, Professor Kimura, former Chairman of the Commission, pointed out that the results from the latitude-station at Mizusawa were inconsistent with those derived from the other stations on the same parallel by an amount which would be reconciled were one to suppose that the Japanese Observatory had drifted southward by about three meters from the position occupied ten years before [4]. Dr. Lambert believes, however, that a real motion of the pole, combined with a systematic error in the proper motions of the stars, provides an equally good explanation. In this case, the latitude of the Russian station at Charjui appears out of line rather than that of Mizusawa. Dr. Lambert would be inclined to attribute the discrepancy to uncertainty in observations.

While Talcott's method of observation utilizing the zenith-telescope offers the highest degree of precision and is that in use at all the International latitude-stations, it is unfortunate that it requires an accurate knowledge of the declination of the stars. The fact that each station utilizes the same stars for observations supposedly makes possible an evaluation of the corrections to the declinations used if such are needed. It has been customary, therefore, to correct star-positions by the results determined from each period of reductions of latitude-observations. This procedure, however, is somewhat unfortunate, since were there any general migration of all stations to or from the equator, such a movement would be completely masked by this process of correction. Comparisons of apparent changes in the declinations of the latitude-stars with their proper motions derived from other astronomical sources, afford a means of ultimately solving the dilmema. There is need for still greater precision in the determination of latitude and a continued examination of the sources of error that may underlie individual discrepancies.

A systematic variation in the observed latitude at the Greenwich Observatory has shown a marked dependence upon the direction and velocity of the wind at the time the star-observations are made, the residuals being plus for north and northeasterly winds and minus for south and southwesterly winds [5]. With the thought that direction and velocity of wind are the indexes to the potential gradient, Professor Brooks has investigated the lateral refraction that may result with the approach and recession of cold fronts in the vicinity of the British Isles. While the magnitude of the refraction that could be thus introduced, he assures us, cannot be greater than one-tenth of a second of arc, even this is a quantity of significance in dealing with the variations observed. It is believed that a comparison of pressure-disturbances over the North Atlantic corresponding to the times of latitude-observations may yield sources of information of help in this connection.

While this report is being written, there has appeared a communication to the Royal Astronomical Society from H. Spencer Jones, Astronomer Royal, concerning the investigation of the variations in latitude at the Greenwich Observatory [5a]. In the analysis of five years' observations with the Cookson floating telescope, it is believed corrections have been made for seasonal variations and wind-effect. A semidiurnal lunar tidal component in the variations has been derived which, when augmented by a correction-factor due to tides in the River Thames, agrees remarkably with values predicted by theory. It should be noted that in treating the observations, corresponding groups of data 12 hours apart were purposely combined in forming the means, thus tacitly assuming a degree of symmetry in the semidiurnal earth-tide.

It is perhaps unfortunate from the point of view of the study of the wandering of the terrestrial pole that three of the four International latitude-stations now in operation are located in regions of more or less geological and meteorological instability. The establishing of another chain of latitude-stations in a subtropical zone, choosing locations of greater geological and meteorological equilibrium, may be desirable. An intercomparison of the results on two different parallels would be of interest. Meanwhile, it is fortunate that latitude-stations in the Southern Hemisphere have been established which in a few years should yield results of importance.

### Variations in longitude

The observational errors encountered in the determination of latitude pertain also to the difference of longitude with the additional difficulty incident to maintaining clocks at constant rates and transmitting time-signals between the two points whose difference in longitude is being measured. The probable error resulting in the value of longitude from a series of observations is a matter of thousandths of seconds of time or the order of ±0.007 second.

Studies of longitude-differences from time-comparisons, however, yield surprising results. In 1931, for example, a redetermination of the longitude between the Argentine National Observatory at Cordoba and the Royal Observatory at Greenwich yielded a value one whole second less than that made under the direction of Dr. Gould in 1871 [6]. Dr. Gould's determination rested upon two very careful longitude-determinations by the United States Navy Astronomical Expeditions which derived independently the longitude of Buenos Aires from Greenwich and that of Valparaiso from Washington, The two determinations made by way of the Atlantic and the Pacific Coast, respectively, gave an agreement within 0.05 second, or a linear uncertainty of about 16 meters.

In the determination of 1931 the time-signals were exchanged by radio in place of cable. The probable error from the 35 nights' observations gave an uncertainty of but 0.007 second, yet the results of the longitude in 1931 differed from that of 1871 by 1.11 seconds, corresponding to a linear distance of 400 meters, an unthinkable difference to be charged to the account of observational errors. Commenting upon the results, Zimmer of the Cordoba Observatory states:

> "Cordoba with respect to Valparaiso and Buenos Aires seems to have been well determined as a comparison of the above values shows, thus clearly demonstrating that whatever error there is in the longitude of Cordoba came in through erroneous determinations of Valparaiso and Buenos Aires. The remarkable thing about it is that the two independent determinations, such as those made by Green and Davis, should be in such complete accord and yet both be wrong by a whole second. We have to assume that those two determinations were in error by at least a round second, since it is impossible to imagine at the present time any such continental drift and especially so since the shift, if there has been any at all, would have had to take place in the opposite direction to that predicted by the theory of Wegener and others."

It is perhaps unfortunate that Zimmer bases his interpretations upon the failure of the resulting difference to agree with the Wegener hypothesis.

While errare est humanum, it seems unthinkable to those acquainted with the details of a longitude-campaign that an error of a whole second should have escaped the well-trained observers of 1871. It seems equally unthinkable that the two determinations, one by way of the Pacific and the other by way of the Atlantic, should have yielded results consistent within 0.05 second, and yet conceal a mistake of 20 times this amount. Making due allowances for slight differences which may have resulted in the comparison of signals by cable in the earlier series as compared with radio in the latter series, is it possible that some of the differences involved may be charged to the geological side of the ledger?

One other outstanding discrepancy in longitude-determinations may be mentioned briefly. It is that involving the position of Sabin Island determined by Jelstrup in 1932 [8] as compared with the position found by Børgen and Copeland in 1869 and 1870 [9]. Jelstrup's new determination, using the identical pier employed in 1870, gave the position 615 meters west of that found from the earlier measures. While Børgen and Copeland did not have the advantage of cable and radio and were obliged to depend upon the more or less unsatisfactory method of lunar observations for determining Greenwich time, examination of the original publications show that the longitude that these observers derived from 16 lunar culminations agreed within 1.5 seconds of their determination based upon four star-occultations. The probable error of the mean of each of the two independent determinations was ±1.1 seconds. This would indicate that the results of Børgen and Copeland were as satisfactory as the circumstances of that time would allow. Jelstrup, using radio communication for determination of Greenwich time in 1932, derived a value for longitude nearly five whole seconds greater than the results of Børgen and Copeland in 1870.

It would appear from the internal evidence of the observations themselves that Jelstrup's observations could not be wrong by much more than 20 meters while the uncertainty of the observations in 1870 was about four times this amount. Nevertheless, if we allow for the worst possible combination of these estimated errors, it would appear that the results in 1932 indicate a longitude farther west by 250 meters from that indicated by the earlier observations.

It should be emphasized that at the same time the latitude resulting from the observations in 1932 was less than that of the observations in 1870 by six seconds of arc, corresponding to a linear distance of 200 meters. Whatever doubt may be cast upon the interpretation of the longitude-differences, it should be emphasized that the latitude-determinations were entirely independent of exchange of time-signals and that the order of accuracy attainable for latitude-determinations in 1870 was nearly as great as in 1932.

The above two instances have been mentioned not in support of any theory or with any attempt to establish continental drift, but are mentioned as examples of the type of facts which must be met and evaluated without prejudice from astronomers who would like their observatories to stay put, or from certain geologists who would like to have the continents moved.

A study of the intercomparison of radio time-signals exchanged across the Atlantic over a period of five years (1929-1934) has revealed variations in the differences much larger than apparently can be accounted for on the basis of observational errors.

The more or less periodic nature of the discrepancies in the determination of time on the two sides of the Atlantic through the examination of radio time-signals, which often occur with more or less rhythm, suggested to Loomis and Stetson a systematic search for any possible correlation for these variations with the hour-angle and declination of the Moon [10]. The results at first yielded surprising changes of the order of 0.05 second that appeared to depend both upon the lunar hour-angle and declination. Characteristics of the resulting curves suggested earth-tidal origin, yet the amplitude appeared too great to be consistent with the theory. Kawasaki has shown [11] that the reversal in phase which might have been attributed to the changing declination of the Moon could be equally well accounted for by an annual term of unknown origin. More recently Professor Schlesinger, utilizing our derived data, has shown that at least the major variations attributable to the declination alone could be satisfied by the introduction of a correction for longitude dependent upon the change of the pole of rotation with respect to the pole of figure [12].

It should be noted that investigations at the Tokyo Observatory have confirmed in a large measure the variations in terrestrial longitude discussed above and bring to light the decrement in amplitude of the measured variations during the years 1934 and 1935 [13]. Recent unpublished investigations by your Chairman show for the earlier years a semidiurnal residual apparently still correlatable with the lunar hour-angle, a variation which practically vanished in 1934 at the time when the two components of the polar motion brought the pole to its mean position.

It has been most unfortunate that since June 1934 the daily intercomparison of transatlantic time-signals between our own Naval Observatory and the Observatory at Greenwich has been interrupted on account of the removal of the 17.6-kc frequency time-signal due to changes in the transmitting station at Annapolis. Through the cooperation of the British Admiralty a short-wave receiver has been installed at the Greenwich Observatory, and, beginning with January 1, 1939, the Washington signal (NAA) at $9^h$ GT has been received on 9425-kc frequency and corrections to these signals have been published in the Admiralty Notices since January 1, 1939. Since, however, the short waves are uncertain during the summer but the low-frequency waves are propagated with reasonable velocity at all seasons and are less subject to ionospheric disturbances, your Committee has urged the reinstatement of the 17.6-kc frequency. As this report was being transmitted to the Union at its twentieth annual meeting, Captain Hellweg, Superintendent of the Naval Observatory and member of our Committee, was happy to announce that through the cooperation of the Navy the noon time-signals (GMT, $17^h$) on 17.6 kc will be reinstated immediately. Plans are now being made through the technical assistance of Dr. Ewing for providing oscillograph recording that will make possible the reception of time-signals at the Naval Observatory with a precision of the order of 0.001 second.

Since the determination of any variations in longitude, real or apparent, must rest upon the fundamental assumption that radio waves are propagated at the same velocity travelling from east to west as from west to east, a project has been submitted and approved by the Planning and Project Committee of our Union for conducting an experiment for the purpose of testing the assumed invariability of velocity of propagation from west to east as compared with the east-to-west direction across the Earth's magnetic field.

The precision obtained by Ewing [14] in determining gravity at sea, using as the timing mechanism of the pendulum-apparatus a crystal chronometer loaned by the Bell Telephone Laboratories to the American Geophysical Union, led us to believe that this timepiece could be profitably employed in testing the fundamental assumption relative to the propagation of time-signals by radio. This project proposes to transport by airplane a crystal chronometer, capable of maintaining a rate uniform within 0.001 second per day, from Langley Field near the Naval Observatory in Washington to a point in the interior of the country some 2000 miles west of Washington, the plane to fly at a speed of approximately 200 miles an hour and to record aboard the plane the signals from Washington as received by the crystal chronometer. Similarly, signals from the moving chronometer would be recorded at the Naval Observatory. Since these time-signals will be received hourly, there should be an apparent cumulative lag in the reception-times of about 0.001 second for each successive hour of flight. Assuming that a continuous flight of seven hours can be made before the termination of the journey, there will be an accumulated lag of 0.007 second by the time the signals are received over the 1400-mile base-line--a time considerably in excess of any expected error of which the crystal chronometer is capable.

In a return journey immediately following, the 0.007-second lag should be reduced by approximately 0.001 second per hour until arrival of the plane again at Langley Field near Washington. The crystal chronometer originally synchronized with the crystal clock at the Naval Observatory should again appear to be in complete synchronization at the end of the experiment. If the experiment performed as just outlined yields consistent results, we should, we believe, have sufficiently verified the fundamental assumption as to the constancy of east-to-west and west-to-east transmission of wireless waves, thus removing all doubt as to the trustworthiness of data depending upon time-signal communication. Should there appear a difference in the lag of the reception of the signals in the return journey from corresponding signals received on the outgoing trip, we should probably have made an even more significant contribution to science.

Detailed plans for the location of a plane and personnel have been completed during the past year but await authorization from the War Department for the utilization of the necessary flying equipment. In accordance with the present policies of utilizing military equipment exclusively for military purposes, the War Department has thus far continued to decline our requests. Search will evidently have to be made for other sources of airway-equipment. It is hoped that, after the crystal chronometer now on loan to the Dutch Gravity Expedition is again returned to the Union, the arrangements may be completed for carrying out so important an experiment to test the validity of a fundamental postulate.

The evidence from a close examination of existing data from previous longitude-campaigns have brought to light apparent variations in the group-velocity of time-signal radio waves that appear to depend upon the geographic or geomagnetic latitude [15]. Since it is evident from such a study that one may no longer assume that radio waves travel with the velocity of light over the great-circle route connecting the two points in question, consideration will have to be given in future longitude-determinations to the location of radio equipment coincident with the station utilized for the star-observations.

A study of the recent investigations by Stoyko and Jouaust reported at the Stockholm Assembly of the International Union of Geodesy and Geophysics leads to the conclusion that the authors believe that a periodical variation in longitude may be easily explained by the pulsation of the Earth's crust without recourse to the displacement of continents [16].

An important contribution by Sollenberger and Clemence has just been communicated in advance of publication to our Committee relative to the detection of any lunar effect in time-observations made at the Naval Observatory with the photographic zenith-tube. A careful analysis by them reveals no variation in time-determinations correlatable with the Moon from observations from March, 1934, to February, 1939, other than what could be accounted for by theory. If the apparent variations in longitude from time-comparisons on the two sides of the Atlantic were due to earth-tidal deformation, one would expect that the results at each of the two observatories concerned would show a certain dependence of its meridian upon the hour-angle of the Moon. However, since complete data for intercomparison of the transatlantic time-signals have not been available since the discontinuance of the 17-kc transmission in 1934, there is no way of comparing results across the Atlantic for the same period for which the observations at Washington have been analyzed.

In addition to the investigations already mentioned which have been completed or initiated, your Committee, in cooperation with the Geological Society of America and the two other Special Committees of the Union, participated in a symposium at the winter meeting of the American Association for the Advancement of Science at Richmond. Certain matters mentioned in this report were presented in connection with the discussion of problems reviewed by the Special Committee on Continents and that on Oceanic Basins. It is obvious that the active work of the two other Special Committees in pursuing researches on gravity and seismology on land and at sea may bring to light regional data of vital consequence to the study of crustal movements. It is hoped that the Special Committee on Cosmic Terrestrial Relationships,from the continuance of the investigations above-mentioned, may add its contributions to the fundamental geophysical studies in which the Union is engaged.

The nature of the work of this Special Committee naturally differs somewhat from that of the other two Special Committees in that a large amount of study of fundamental questions is involved as well as the initiation of certain experiments and observations. This first report must therefore, in a sense, remain preliminary.

There are many other problems involving important cosmic terrestrial relationships already recognized which in due course may well receive the attention of your Special Committee. It is your Committee's opinion, however, that for the present a continuation of the study of the problems above-outlined, involving the question of variations in geographic coordinates, the exchange of time-signals, and a study of the peculiarities of radio propagation so important in the determination of longitude, should occupy its principal attention.

The Committee will take this occasion to express its appreciation for the cooperation which has been received from Government agencies and scientific experts who have interested themselves in the difficult problems whose investigation has been undertaken.

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Massachusetts Institute of Technology,
Cambridge, Massachusetts, April 1939

## APPENDIX E--REPORT OF SPECIAL COMMITTEE ON GEOPHYSICAL AND GEOLOGICAL STUDY OF CONTINENTS

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G. P. Woollard

### Introduction

Scientific border-lines which once existed between theoretical and exploratory geophysics, between theoretical and exploratory geology, and between exploratory geophysics and exploratory geology have now practically vanished. Geochemistry is similarly united in a continuous and coherent scientific field, and numerous other branches or fields of natural science are now rapidly manifesting their close relationships and mutual interdependence as parts of the general field of a unified Earth science.

A great number of individuals are doing splendid work in advancing the geophysical-geological study of North American areas. These include: The Society of Exploration Geophysicists; the Geophysical Section of the American Institute of Mining and Metallurgical Engineers; the Geological Society of America; the American Association of Petroleum Geologists; the telephone, telegraph, and broadcasting companies; mining, oil, and other companies; and dozens of Federal, State, and privately endowed organizations and agencies. All of these have been carrying forward one or more phases of geophysical-geological exploratory work as related to continental areas. Consequently, the chief functions of this Special Committee of the American Geophysical Union have been to facilitate collaboration in research, to stimulate new geophysical-geological experimentation--particularly within coastal areas from which marine exploration could be most easily undertaken and projected; and to undertake compilations for which it has had special facilities or opportunities.

## Work done during the past year

Gravity-profile work--Within the past year the Committee has assisted in the development of collaborative arrangements between several State and Federal agencies which led to the establishment of 11 gravity-profiles of considerable length (and of large scientific significance) in the Gulf Coast and Atlantic Coastal Plain regions. These profiles were chiefly in Alabama, Florida, Georgia, North Carolina, Virginia, Maryland, and New Jersey.

Seismic-profile work--Due chiefly to the assistance of the Geological Society of America and the State Geologist of New Jersey, further seismic determinations of the depth to the basement-surface were made along profiles in New Jersey.

"Basement-surface" map--During the year a new regional map covering the eastern two-thirds of the United States was compiled to show by thousand-foot contours the configuration of the "basement-surface" between the Atlantic Coast and the eastern edge of the Great Basin. This map, which is on a horizontal scale of 1/2,500,000, has since been converted into a relief-model, of a like horizontal scale, and with a fivefold exaggeration in vertical scale.

"Gravity-anomaly" map--A new gravity-(iso-anomaly) map of the eastern United States has also been compiled (by Dr. G. P. Woollard), using the new gravitational data which have just become available, and this new compilation shows numerous and significant parallelisms between gravitational "positive strips" and "negative strips" and the fundamental structural trends of the Appalachian Mountains. The evidence so provided bids fair to supplement in several very significant ways that previously yielded by the studies of the "negative strips" of the East Indian and West Indian regions.

Symposium on the Geophysical and Geological Study of Continental Borders--On behalf of the Union, and in collaboration with the Union's Special Committees on Oceanic Basins and on Cosmic Terrestrial Relationships, the Special Committee on Continents took part in the presentation of a "Symposium on the Geophysical and Geological Study of Continental Borders." This Symposium was presented before a joint session of Sections E and D of the American Association for the Advancement of Science, held at Richmond, Virginia, on December 27, 1938.

## Work in progress

Collaborative exploration of continental borders--Additional geophysical-geological studies are under way in continental-border areas, as researches in which both Special Committees of the Union on Oceanic Basins and on Continental Structure are collaborating with each other and with a number of State, Federal, and non-governmental research agencies. Gravitational, seismic, and magnetic methods are to be employed in this work.

Cosmic terrestrial-tectonophysical studies--Extensive planning and research is now in progress between members and groups within this Special Committee's membership and between this Committee and the Union's Special Committee on Cosmic Terrestrial Relationships in order to define and solve (as rapidly as possible) the problems connected with (1) "the physics of elastic deformation, flow, and rupture of the constituent materials of the Earth," and (2) the roles of cosmic forces and influences in inducing terrestrial deformations and transformations. The nature and need for expanded work along tectonophysical lines is being pointed out in a memorandum to the Union now in preparation by a Committee consisting of L. H. Adams, A. F. Buddington, James Gilluly, D. T. Griggs (Chairman), and M. K. Hubbert.

Type-map collection--Work is still progressing on the collection (and compilation) of type-maps showing geophysical depiction of either local or regional geologic conditions of scientific significance.

### Committee recommendations

Depository for geophysical data--It is becoming increasingly evident that there is great need for a depository in which current geophysical maps and reports may be placed for safekeeping--if need be, under stipulation that certain material is to be held as confidential until the expiration of a specified period. Such a depository is urgently needed now as an aid to current research, and would soon become of great practical value in the future progress of natural resource exploration.

Geophysical-geological compilation-work--There are abundant opportunities for the compilation of non-confidential geophysical-geological data of great interest and importance. Funds are not as yet available for this work, but its cost will be infinitesimal in proportion to its interest and importance.

Establishment of geophysical bench-marks--A nation-wide network of gravitational and magnetic bench-marks should be completed at the earliest possible moment--as a most valuable aid both to research science and to practical exploration--since without a unified system of reference-points the necessary comparability cannot be had between sets of similar data from different parts of the country. It is to be hoped that the Federal Government will soon more fully recognize and meet its responsibilities in this direction.

Princeton University,
Princeton, New Jersey

## APPENDIX F--REPORT OF THE CHAIRMAN OF THE ORGANIZING COMMITTEE FOR THE SEVENTH TRIENNIAL ASSEMBLY OF INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

It seems unnecessary to give a lengthy report at this time since most of the information regarding the present status of affairs relating to the Meeting has been given in the several circulars which have been issued to the full membership of the American Geophysical Union including a complete list of the personnel of the Organizing and other Committees. It suffices to state that preparations have proceeded in a normal manner, with due regard to world conditions, which have made it necessary at all times to have in view the possible cancellation of the Meeting. For some of the Committees the time has now come for intensive effort with less regard to such a contingency.

Further, the period of more or less informal action, chiefly relating to the exploration of the possibilities, has now passed and the chief work before the Committees is to carry out definite, established plans. The important Finance Committee, of which R. M. Field is Chairman, is approaching practical completion of its work, though Congress has not yet acted finally on the request for an appropriation of $5000. However, the financial situation is satisfactory with at least $12,000 in sight, exclusive of that amount. The total amount is no more than needed for a successful meeting. Thanks for important contributions are due to the National Research Council, the Geological Society of America, the Carnegie Corporation of New York, and other organizations and many individuals.

The Committees may be considered in three groups: Meeting; entertainment; and related activities. Those related to the Assembly include: Local Secretaries, which has to do with the program; Meeting Places; and Office (which includes a wide variety of activities at the time of the Assembly). All of these have made good progress. The general Entertainment and Ladies' Entertainment Committees have their plans well established. Related activities include: Committee on Coordinated Interests, which has made excellent progress in securing the interest and cooperation of many organizations; Publicity, which has made a good start but whose main activity is at the time of the Assembly; Travel, which takes care of organized trips before the Assembly; and Exhibits, which is providing for certain exhibits at the George Washington University, and related exhibits elsewhere. General activities are being coordinated with activities for the several Associations, which include at least a half-day for demonstration-trips relating to their special fields, and in the case of hydrology an extended trip after the Assembly.

(Signed) N. H. Heck, Chairman

## APPENDIX G-a--MINUTES OF THE ANNUAL MEETING APRIL 27, 1939, SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION

The meeting was held in the Library of the National Academy - Research Council Building, Washington, D. C., April 27, 1939. The meeting was called to order by the President, C. H. Swick, at 9:03 a.m. and adjourned at 11:52 a.m. The registered attendance was 83.

The President called attention to the fact that the minutes of the nineteenth annual meeting held April 27, 1938, had been printed and sent out to the members and that no corrections had been received. The minutes were declared approved as printed and circulated.

The Secretary submitted a brief report [see Appendix G-a(1)] in regard to preparations for the General Assembly of the International Union of Geodesy and Geophysics to be held in Washington in September, 1939, and gave a summary of the items that had been prepared and submitted to the General Secretary of the International Association of Geodesy as suggestions for the agenda of the Washington Assembly.

There were no officers to be elected and no resolutions were submitted. The Section therefore proceeded to hear the papers on the scientific program as published in these Transactions [pp. 305-331].

After the report of the Committee on Relation of Inch and Meter was presented by R. M. Wilson, a motion was made that the majority report of the Committee be approved by the Section of Geodesy. This motion was seconded and, after discussion, was passed.

At the close of his paper on "Procedure at meetings of the International Association of Geodesy and of the International Union of Geodesy and Geophysics," W. D. Lambert made the following motion which was seconded and passed:

> "Moved that American members of this Section duly appointed to membership in the Committees of the International Association of Geodesy, either to regular membership or to membership for the duration of the International Assembly only, be designated as qualified to vote on scientific questions coming before the Association of Geodesy and that other members of the American Section of Geodesy, though technically entitled to vote, be requested to abstain from voting, both as a matter of courtesy to foreign delegates and as a matter of good policy. It is understood that this scheme of voting automatically includes Americans already members of international scientific committees."

(Signed) Walter D. Sutcliffe, Secretary,
Section of Geodesy

## APPENDIX G-a(1)--REPORT OF THE SECRETARY, SECTION OF GEODESY, AMERICAN GEOPHYSICAL UNION, APRIL 27, 1939

During the past year the Executive Committee of the Section of Geodesy held several meetings in connection with the General Assembly of the International Union of Geodesy and Geophysics to be held in Washington in September, 1939. We received a request from General Perrier, Secretary of the International Association of Geodesy, for items for the agenda of the General Assembly. Since it was impracticable to hold a special meeting of the Section of Geodesy to consider items for the agenda, letters were written to about 25 members of the Section asking for suggestions.

Replies were received from ten members, some of which contained very valuable suggestions. The Executive Committee, assisted by W. D. Lambert, considered these suggestions and prepared five items for the agenda which have been forwarded to General Perrier. The Executive Committee also approved a resolution prepared by Mr. Lambert on the subject of earth-tides, and this has also been sent to General Perrier.

I wish to take this opportunity to thank the various members of the Section who have assisted the Executive Committee by furnishing suggestions for items of the agenda and especially Mr. Lambert for his very valuable assistance in preparing the items in the proper form.

The following items have been submitted to General Perrier:

(1) The Association of Geodesy calls attention to the known variability of the vertical

gradient of gravity and expresses the hope that it may be studied with the aid of recently developed sensitive gravimeters.

(2) The Association of Geodesy wishes to express anew its desire that Resolution XX on the determination of the geoid (Union Géodésique et géophysique internationale; sixième Assemblée générale réunie à Edimbourg: Camelot Press Limited, London and Southampton, 1937, pp. 62-63) be put into effect. In addition to the observations recommended in this Resolution, the Association desires an increase in the number of observations with the torsion-balance to be correlated with other observations in determining the geoid.

(3) The Association of Geodesy deems it desirable for the various countries to establish comprehensive nets of gravity reference-stations as rapidly as possible in order that local geophysical surveys related to the gravitational field may be coordinated whenever this is feasible.

(4) The Association of Geodesy wishes to emphasize the importance of accurate measurements of crustal movements in both a vertical and a horizontal direction. A knowledge of these movements is not only important as affecting the permanence of geodetic surveys and markers but is of much value to seismologists in investigations of the occurrence of earthquakes.

(5) The Association of Geodesy wishes to encourage experimental tests in the protection of survey-markers from frost-action under various climatic conditions.

(Signed) Walter D. Sutcliffe, Secretary,
Section of Geodesy

## APPENDIX G-b--MINUTES OF THE ANNUAL MEETING APRIL 27, 1939, SECTION OF SEISMOLOGY, AMERICAN GEOPHYSICAL UNION

The meeting was called to order by the President, the Rev. J. B. Macelwane, S.J., at 2:00 p.m. in the Library of the National Academy - Research Council Building, Washington, D. C. Thirty-nine persons registered their attendance. Speaking at the first meeting of the Section after assuming office, the President commented briefly on the activities of the Section and solicited the cooperation and advice of members in conducting its affairs.

The Secretary made an informal report on cooperation extended the Secretary of the International Seismological Association in obtaining station and instrumental constants of American stations for a new list of seismological stations of the world now in preparation at Strasbourg.

The President appointed the following Resolutions Committee: H. Landsberg (Chairman), D. Linehan, S.J., and O. W. Swainson. After due consideration and some discussion from the floor, resolutions were adopted commending the Special Committees of the American Geophysical Union engaged in studies of oceanic and continental structure for the impetus given seismological research through their achievements, and also commending the work of various Special Committees of the Eastern Section of the Seismological Society of America. [The three resolutions appear as resolutions (2), (3), and (4) in the minutes of the General Assembly of the Union.]

The Nominating Committee previously appointed by the President [M. Ewing (Chairman), J. Lynch, S.J., and R. R. Bodle] nominated F. Neumann to succeed himself as Secretary of the Section for the three-year period ending June 30, 1942. There were no other nominees and the candidate was duly elected.

N. H. Heck presented the only paper on the program, discussing, among other things, methods of procedure at international assemblies of the Union. Following this presentation, a motion was adopted to empower the Executive Committee of the Section to designate the number of American delegates to vote on scientific questions in seismology at the Seventh Assembly of the International Union of Geodesy and Geophysics, making the number comparable with the size of foreign delegations. The Secretary then gave a resumé of the program of American papers and items for discussion as submitted through the Section to date.

The session adjourned at 2:45 p.m.

(Signed) Frank Neumann, Secretary,
Section of Seismology

## APPENDIX G-c--MINUTES OF THE ANNUAL MEETING APRIL 27, 1939, SECTION OF METEOROLOGY, AMERICAN GEOPHYSICAL UNION

The twentieth annual meeting of the Section of Meteorology, President Weightman presiding was held from 9:15 a.m. to 12:25 p.m., Thursday, April 27, 1939, in the Lecture Room of the National Academy - Research Council Building, Washington, D. C. One hundred and two members and guests registered attendance, but the actual number was greatly in excess of this as many did not register. The reading of the minutes of the previous meeting was dispensed with, as they had already been printed in the Transactions of the nineteenth annual meeting of the Union and no corrections had been received.

The Secretary made a number of announcements concerning the Assembly of the Association of Meteorology of the International Union of Geodesy and Geophysics to be held at Washington, D. C., in September 1939, emphasizing the necessity of communicating titles and summaries of papers for inclusion in the final program to the General Secretary of the Association not later than June 1, 1939.

The Committee on Resolutions [H. R. Byers (Chairman) and R. T. Zoch] presented a resolution on long-range weather-forecasts, which was accepted by the Section and referred to the Committee on Resolutions of the Union. [This is Resolution (1) given in the minutes of the General Assembly of the Union.]

There being no further business, the scientific program was presented including the papers printed in these Transactions [pp. 337-356].

(Signed) H. D. Harradon, Secretary,
Section of Meteorology

## APPENDIX G-d--MINUTES OF THE ANNUAL MEETING APRIL 26-27, 1939, SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY, AMERICAN GEOPHYSICAL UNION

Because of the large number of papers submitted for presentation, the twentieth annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union was divided into two sessions.

The first session was held in the Auditorium of the National Museum, Washington, D. C., on April 26, 1939. The meeting was called to order by President E. O. Hulburt at 9:22 a.m. The report of the Secretary was read and approved [see Appendix G-d(1)]. There being no further business, the Section proceeded to the scientific part of the program, and the first eleven papers published in these Transactions [pp. 358-374] were presented. The meeting adjourned at 12:18 p.m. The registered attendance was 73.

The second session was held in the Library of the National Academy - Research Council Building, Washington, D. C., on April 27, 1939. The meeting was called to order by President E. O. Hulburt at 2:55 p.m. and proceeded directly to the presentation of the remaining eleven papers published in these Transactions [pp. 374-391].

Following Dr. J. A. Fleming's discourse on the procedure at international meetings, it was moved and seconded that, as a courtesy to foreign delegations at the forthcoming meeting of the International Union of Geodesy and Geophysics in Washington in September, 1939, in all voting on scientific questions the number of votes of the American delegation to the meetings of the Association of Terrestrial Magnetism and Electricity be restricted to a number comparable to that of the largest foreign delegation, and that the Executive Committee of the American Geophysical Union be authorized to designate the number of persons to so vote. The motion was carried.

The meeting adjourned at 5:30 p.m. The registered attendance was 59.

(Signed) J. W. Joyce, Secretary,
Section of Terrestrial Magnetism
and Electricity

## APPENDIX G-d(1)--REPORT OF THE SECRETARY TO THE TWENTIETH ANNUAL MEETING OF THE SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY

No special meetings of the Section were held during the year. The minutes of the nineteenth annual meeting were published in the Transactions. No corrections or additions have been received.

During the past year, Science Service has continued the dissemination of the American magnetic character-figure, based on reports received from the seven American-operated magnetic observatories of the Coast and Geodetic Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.

Preliminary notices of the twentieth annual meeting were distributed to all members through the office of the General Secretary under date of February 26, 1939.

The British Admiralty's non-magnetic ship Research was successfully launched on April 4, 1939. Present plans, which may of course be changed, will bring the Research to the United States in February of 1940. In appreciation for the assistance given by the Department of Terrestrial Magnetism to the British Admiralty in making available during the course of the vessel's construction the services of W. J. Peters as an expert consultant in matters pertaining to instruments and equipment, it is planned to make Washington the first port of call.

Progress-reports in the field of terrestrial magnetism and electricity have been received from the following:

National Astronomical Observatory, Mexico--Operation of magnetic observatory and some secular-change observations in the field.
National Bureau of Standards--Continued ionospheric researches, dissemination of ionospheric and radio-transmission conditions, observation of ionospheric storms, and radio-wave propagation.
United States Coast and Geodetic Survey--Operation of five magnetic observatories, magnetic survey, reduction of magnetic data, instrumental developments, structural improvements at observatories, dissemination of magnetic data for nautical charts, cooperative programs with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.
Department of Terrestrial Magnetism, Carnegie Institution of Washington--Operation of two magnetic observatories, reduction of magnetic data, atmospheric and terrestrial electricity, ionospheric research, nuclear high-voltage investigations, cosmic rays.

The above reports will be incorporated in the Transactions of the twentieth annual meeting [see pp. 392-397].

The total membership of the Section is 230, an increase of 17 over last year.

(Signed) J. W. Joyce, Secretary,
Section of Terrestrial Magnetism
and Electricity

## APPENDIX G-e--MINUTES OF THE ANNUAL MEETING APRIL 28, 1939, SECTION OF OCEANOGRAPHY, AMERICAN GEOPHYSICAL UNION

The annual meeting of the Section of Oceanography was held at Washington, D. C., Friday, April 28, 1939, in the Library of the National Academy - Research Council Building. The meeting was called to order by President C. O. Iselin at 9:05 a.m. Some 80 members and guests were present.

The minutes of the previous meeting, having been distributed to the members and there being no corrections or additions, were approved.

The President called for any unfinished business from the members present. There being none, papers were presented as printed in these Transactions [pp. 399-427].

With regard to the paper read by Dr. Hess on a new bathymetric chart of the Caribbean Area, there were many expressions of gratitude to the Hydrographic Office for its cooperation in obtaining the data for this chart.

The meeting adjourned at 11:50 a.m.

(Signed) Paul A. Smith, Acting Secretary,
Section of Oceanography

## APPENDIX G-f--MINUTES OF THE ANNUAL MEETING APRIL 26, 1939, SECTION OF VOLCANOLOGY, AMERICAN GEOPHYSICAL UNION

The session of the Section was called to order at 2:04 p.m. by President E. G. Zies in the Auditorium of the National Museum and was concluded at 4:45 p.m. In the absence of Secretary James Gilluly, Eugene Callaghan acted as Secretary at the request of the President. The reading of the minutes of the previous meeting was dispensed with, as the minutes had been published in the Transactions of the nineteenth annual meeting. Seventy-three members and guests were present.

The papers were then presented as printed in these Transactions [pp. 429-452].

(Signed) James Gilluly, Secretary,
Section of Volcanology

## APPENDIX G-g--MINUTES OF THE ANNUAL MEETING APRIL 27-29, 1939, SECTION OF HYDROLOGY, AMERICAN GEOPHYSICAL UNION

The Section of Hydrology held three sessions in the National Academy - Research Council Building on April 27 and 28, 1939, and a round-table discussion in the Building of the United States Department of the Interior on April 29, 1939.

The first session was called to order at 9:15 a.m., April 27, in the Auditorium. President Sherman presided during the first part of the session, and C. S. Jarvis during the second part. The President appointed the following Committee on Resolutions: Francois E. Matthes (Chairman) Bertram Barnes, and Waldo E. Smith. Thirteen papers and reports of committees were presented [printed in Part IV of these Transactions]. Eighty-four members and guests were present. The session adjourned at 12:40 p.m.

The second session was called to order as a business meeting at 2:05 p.m., April 27, in the Auditorium by President Sherman. The minutes of the annual meeting in 1938, as published in the Transactions of 1938, Part I [pp. 581-584], were approved. The President reported informally on the activities of the Section for the past year. The Nominating Committee [D. G. Thompson (Chairman), R. S. Goodridge, C. R. Hursh, S. T. Harding, W. B. Langbein, E. R. Leach, F. T. Mavis, and F. J. Veihmeyer] made the following nominations for officers to serve for three years beginning July 1, 1939: N. C. Grover for President, M. P. O'Brien for Vice-President, and K. H. Beij for Secretary. There being no further nominations, a motion made and seconded that the nominations be closed and the Secretary cast a unanimous ballot for the nominees was passed. The President declared the nominees elected. There being no further business, the business meeting was adjourned. The session resumed with N. C. Grover presiding. Thirteen papers and reports of committees were presented [printed in Part IV of these Transactions]. Seventy-six members and guests were present. The session adjourned at 5:00 p.m.

The third session was called to order at 9:15 a.m., April 28, in the Auditorium. President Sherman presided during the first part of the session, and M. Bernard and R. W. Davenport during the second part. The Committee on Resolutions presented the following resolutions which were adopted unanimously:

(1) WHEREAS, LeRoy K. Sherman, during his incumbency as President, has inspired the Section of Hydrology by his able leadership, has materially strengthened its organization and stimulated the activity of its research committees, and by his own example and personal counsel has afforded kindly encouragement to the younger hydrologists, therefore be it

RESOLVED, That the Section of Hydrology express to him its high appreciation and gratitude, and that the Secretary hereby is instructed this resolution on the minutes of the meeting and convey a copy to Mr. Sherman.

(2) WHEREAS, J. E. Church, during his term as Vice-President, has contributed significantly to the splendid progress that has been made in those lines of research relating to the hydrology of snow, and through his own personal enthusiasm has kindled like enthusiasm in the other workers in this field, therefore be it

RESOLVED, That the Section of Hydrology express to him its high appreciation and gratitude, and the Secretary is hereby instructed to spread this resolution on the minutes of this meeting and convey a copy to Professor Church.

(3) WHEREAS, K. Hilding Beij, in his capacity as Secretary, has served the Section of Hydrology with exemplary devotion, diligence, and efficiency, thereby contributing to the success attained by the Section in its work and as a component part of the American Geophysical Union, therefore be it

RESOLVED, That the Section of Hydrology express to him its sincere appreciation and gratitude, and the Secretary is hereby instructed to spread this resolution on the minutes of this meeting.

Twelve papers and reports of committees were presented [printed in Part IV of these *Transactions*]. Eighty-seven members and guests were present. The session adjourned at 12:50 p.m.

The round-table conference was called to order at 9 a.m., April 29, in Room 5243 of the Interior Department Building. President Sherman introduced W. G. Hoyt, M. Bernard, and W. B. Langbein, who presented the subjects for discussion. The paper "Some general observations of physiographic and climatic influences on floods" by W. G. Hoyt and W. B. Langbein was used as a vehicle for discussion, but much time was also devoted to related subjects. With a brief intermission for lunch, the discussion continued to 4:30 p.m. The papers submitted in this Symposium are printed as Part II of these *Transactions*. About seventy members and guests were present.

The total registration of members and guests at the regular sessions and the round-table discussion was 159.

(Signed) K. Hilding Beij, Secretary,
Section of Hydrology

## APPENDIX G-g(1)--REGIONAL COMMITTEES OF THE SECTION OF HYDROLOGY

North Continental Divide Area

O. W. Monson, Chairman
D. B. Freeman
H. T. Gisborne
G. A. Hathaway
C. S. Heidel
James C. Marr
W. E. Maughan
William A. Rockie
A. H. Tuttle

South Continental Divide Area

Royce J. Tipton, Chairman
G. D. Clyde
Ivan C. Crawford
Robert Follansbee
Ivan E. Houk
Berkeley Johnson
George S. Knapp
M. F. McArdle
Ralph R. Parshall
H. T. Person
Samuel Shulits
C. V. Theis
Ralf Woolley

North Pacific Coast Area

Glenn L. Parker, Chairman
C. H. Canfield
R. C. Farrow
Joseph Jacobs
L. T. Jessup
Norbert H. Leupold
Fred Merryfield
J. H. Ryan
R. K. Tiffany
R. G. Tyler
C. E. Webb

South Pacific Coast Area

M. P. O'Brien, Chairman
H. F. Blaney
J. E. Church
Harold Conkling
C. E. Elder
S. T. Harding
M. R. Huberty
Charles J. Kraebel
D. Arnold Lane
C. H. Lee
S. B. Morris
Fred S. Scobey
Franklin Thomas
F. J. Veihmeyer
Baldwin M. Woods

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